NOAA Technical Memorandum NMFS-NE-218

NEUS – Atlantis: Construction, Calibration, and Application of an Ecosystem Model with Ecological Interactions, Physiographic Conditions, and Fleet Behavior

US DEPARTMENT OF COMMERCE
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NEUS – Atlantis: Construction, Calibration, and Application of an Ecosystem Model with Ecological Interactions, Physiographic Conditions, and Fleet Behavior

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ABSTRACT

Ecosystem Based Fishery Management (EBFM) and ecological considerations in a multispecies context are increasingly being recognized as important for maintaining ecosystems and their associated marine resources. However there are currently relatively few fishery and ecosystem models which take into account EBFM- related issues and associated ecological considerations. One such model is Atlantis, which has been used extensively in Australia to inform fishery management plans. Atlantis is a series of submodels (biological, geophysical, fishing, assessment, and management) and as a whole simulates a Management Strategy Evaluation (MSE) procedure which allows for qualitative comparisons of different management choices. We have parameterized Atlantis for the Northeast United States Continental Shelf Large Marine Ecosystem (NEUS LME), including the major functional groups from an ecosystem perspective. We have also parameterized and simulated the physiographic dynamics of the ecosystem, as well as the most important fleets. Our goal was to recreate, at least in approximate terms, the biomass, catch, and effort trends in the NEUS LME from 1964 to the mid 2000s. Here we document this Atlantis application for the NEUS LME and describe the various levels of calibration to establish a reference base for future utilizations of this particular application of the Atlantis model that will evaluate different management strategies and their tradeoffs. Our preliminary results demonstrate that Atlantis can reasonably approximate time series and spatial distributions for the majority of main processes and state variables of the most important functional groups and fisheries in the NEUS LME, given the levels of calibration tolerance for such a multivariate, multispecies, multifactorial modeling approach.

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INTRODUCTION

The Value of EBFM

There have been numerous prescriptions and admonitions to implement ecosystem-based fisheries management (EBFM) (Larkin 1996; Link 2002a, 2002b; Garcia et al. 2003; Browman and Stergiou 2004, 2005). The justifications and rationales for adopting EBFM have been previously noted (Larkin 1996; Botsford et al. 1997; NMFS 1999, Link 2002a; Garcia et al. 2003) as an enhancement of or improvement over the current, single stock/species (SS) approaches to fisheries management and science. In particular, the benefits of EBFM generally are: (1) categorically more conservative (precautionary) management recommendations; (2) explicit consideration of nontargeted species, protected species, habitats, etc. (i.e., the ecosystem as a whole) with appropriate precaution built in to the exploitation regimes; (3) direct consideration of tradeoffs among and within sectors and also tradeoffs across biomass allocation; (4) the potential for simpler management institutions; (5) improved short- and long-term economics for participating fishers; and (6) long-term sustainability for intergenerational equity.

An ecosystem approach provides several advantages over SS approaches. As has been noted, EBFM: (1) addresses effects of fishing on nontarget species, habitat, ecological interactions, and system-wide processes; (2) recognizes that marine ecosystems provide "goods and services" other than fishery harvest; (3) explicitly addresses biomass tradeoffs (in our view the key to the entire issue); (4) increases leverage from new stakeholders; and (5) changes the burden of proof. Even if SS approaches were executed entirely correctly (as some have argued as all that is required for EBFM; e.g. Mace 2004; Hilborn 2004 (in Browman and Stergiou 2004); Eagle 2008 (in Leslie et al. 2008)) there are still many factors that would not be adequately addressed. Although the debate continues (Mace 2004; Hilborn 2004 section in Browman and Stergiou 2004; Eagle's perspective in Leslie 2008), there is an emerging recognition that EBFM and ecosystem approaches to fisheries (EAF) management are necessary. In simplest terms, EBFM and related ecosystem approaches to management (EAM) may provide a way to avoid negatively fulfilling Graham's Law of overfishing and to also address the other, multiple-sector societal concerns that are currently difficult to handle in fisheries. There is a clearly recognized need to be holistic, coordinated, and integrated in our approach to living marine resources (LMR) management.

There have been relatively few instances where such an approach has been implemented (Pitcher et al. 2009), but the number is growing as fisheries scientists, managers, and stakeholders grapple with the specific details of executing EBFM (Pitcher et al. 2009). As a discipline and as a practice, fisheries scientists and managers are now clearly beyond the whys and whats of EBFM (Murawski 2007) and squarely in the middle of the hows. That is, we are now well underway in the transition towards novel ways of assessing and managing LMR. While some have noted (Pitcher et al. 2009) that a full implementation of EBFM is still distant, steps to that end are extant.

The Value of Ecosystem Models

There are numerous methodological approaches that can facilitate the scientific basis for the implementation of EBFM. These include: (1) development of fisheries systemic indicators, particularly those empirically based from longstanding fisheries and oceanographic monitoring surveys; (2) statistical evaluation of said surveys, both from a time series and multivariate sense;

(3) process-oriented studies (in vivo and in situ) to more fully elucidate those ecological (usually trophic) and environmental relationships to LMRs of interest; (4) ecosystem comparisons to determine unique and general marine ecosystem properties; (5) exploring the range of EBFM options in a process that is adaptive (e.g., Integrated Ecosystem Assessment (IEA), Management Strategy Evaluation (MSE), Risk Analysis); and (6) implementing the full range of ecosystem modeling endeavors. This latter item can be thought of as in silico studies that explore the relative importance of ecosystem processes and the robustness of various management strategies. Ecosystem models are clearly an important part of implementing EBFM, and many of the approaches noted above utilize ecosystem models and their outputs as a key component of those efforts.

There have been very useful summaries of the range of ecosystem models that are germane for EBFM (Hollowed et al. 2000; Whipple et al. 2000; Plagányi 2007; Townsend et al. 2008; FAO 2008). These models cover the gradient noted in Link (2002a) from SS to full system models, with numerous modeling options along that gradient of complexity and realism. At various points along that gradient, multiple models can address a range of questions or issues. As noted in Townsend et al. (2008, their Table A.3), the types of model classes being employed need to correspond to the appropriate set of questions and issues. Few models are extant that can cover the full range of biophysical, ecological, environmental, harvest, and human management processes. Such a model allows one to explore a range of scenarios across ocean-use sectors and to simultaneously account for a wider range of processes than is usually done in more minimally realistic models.

The Value of This Model

One approach to executing ecosystem models in an EBFM is to use the Atlantis model package. Atlantis has the benefits of being able to model a wide range of factors, processes, and considerations concurrently. It has the advantage of not locking into any one functional form of a given process nor requiring the application of every possible process, and as such it is rather modular and adaptive in design. Atlantis was originally designed to explore a range of management scenarios in a fisheries management context in Australia, directly accounting for ecosystem considerations. As such, its application to other ecosystems has similar utility.

The purpose of this document is to provide a brief background of Atlantis models, describe some of the main equations and model structure used in Atlantis, provide some of the key parameters as used in the Atlantis NEUS modeling effort, describe the general Atlantis NEUS modeling and calibration process, and present some preliminary results.

OVERVIEW OF ATLANTIS

Atlantis (Fulton et al. 2004a, 2004c, 2004d) is an ecosystem "box" model intended for use in management strategy evaluation (as described in de la Mare 1996; Cochrane et al. 1998; Butterworth and Punt 1999; Sainsbury et al. 2000). It has been applied to multiple marine systems (from single bays to millions of square kilometers) in Australia and the United States.

Atlantis incorporates multiple alternative submodels to represent each step in the management strategy and adaptive management cycles (Figure 1), though some steps are more extensive than others (e.g., the biophysical and fisheries submodels). The core of Atlantis is a deterministic biophysical submodel that is spatially resolved in three dimensions by using a map made up of boxes and slab-like layers. This model tracks the nutrient (usually nitrogen and silicate) flows through the main biological groups found in the marine ecosystem of interest. The primary ecological processes considered in the model are consumption, production, waste production and cycling, migration, predation, recruitment, habitat dependency, and mortality. Atlantis treats lower (invertebrate) trophic levels as biomass pools (though cephalopods and prawns may have some age structure), while the vertebrates are represented with an age- and stock-structured formulation (which tracks the condition of average individuals). The physical environment is also represented explicitly with a set of polygons matched to the major geographical and bioregional features of the simulated marine system. Polygonal maps allow the model to focus the spatial attention where needed, capturing the critical dynamics while still achieving computational efficiency (Nihoul and Djenidi 1998; Fulton et al. 2004b). The biological components are replicated in each layer of each of these polygons. Movement between the polygons is by advective transfer or directed movements (depending on the variable), which are modeled as inputs from the output of a range of hydrodynamic models, used accordingly for each ecosystem.

Atlantis also features a detailed exploitation model. This model deals with the impacts of pollution, coastal development, and broadscale environmental change but is focused on the detailed dynamics of fishing fleets. It allows for multiple fleets, each with its own characteristics regarding gear selectivity, habitat association, targeting, effort allocation, and management structures. At its most complex, this exploitation submodel includes explicit handling of economic drivers, compliance decisions, exploratory fishing, and other complicated real world concerns such as quota trading.

The exploitation model interacts with the ecosystem, but also supplies simulated “data” (derived from the exploitation model) to a sampling and assessment submodel. As Atlantis is primarily used in Management Strategy Evaluation, it includes both operating biophysical and fisheries submodels and assessment submodels so that the efficacy of monitoring and assessment models can be considered along with any management strategies. The sampling and assessment submodel in Atlantis generates sector dependent and independent data with realistic levels of measurement uncertainty (bias and variance). These “simulated data” are based on the outputs from the biophysical and exploitation submodels, given a user-specified monitoring scheme. By handling the monitoring of the system in this way, a wide range of combinations of fisheries and survey information can be mimicked from landings data only to onboard catch composition monitoring by observers and intensive independent surveys. These “simulated data” are then fed into the same assessment models used in real-world stock assessments (including Surplus Production, Adapt Virtual Population Analysis (VPA) and Bayesian integrated assessments). In addition to these traditional assessment methods, a range of ecological indicators can be calculated with an eye to their potential role in future ecosystem-based management schemes as thresholds of decision criteria.

The output of the assessment models is fed to the management model (typically a set of decision rules and management levers) for action. The management model in Atlantis is currently only detailed for the fisheries sector. This includes an extensive list of potential management levers: gear restrictions, days-at-sea, quotas, spatial and temporal zoning, discarding restrictions, size limits, bycatch mitigation, and dynamic reference points, etc. It is also possible to track a crude index of the costs of management (mainly monitoring and enforcement costs).

Atlantis’ greatest strength is its modular construction. A wide range of alternative assumptions and model implementations is provided in Table 1. This construction allows the user greater freedom to set the complexity at the desired level – from a few groups with simple trophic interactions and a simple catch equation to extensive models, with complicated stock structure, multiple fleets, detailed economics, and multiple management levers (input, output, and spatial). A lot of developmental attention has also been given to the model's ability to capture age-size dependencies and temporal and spatial variation so that it produces realistic ecosystem dynamics, both temporally and spatially (Fulton et al. 2004c). From a user's point of view, this flexibility and mechanistic basis does, unfortunately, make the model both process- and parameter-intensive. This flexibility and resulting complexity can make validation quite time consuming and can also lead to large uncertainties. This issue is much less of a problem within the strategic setting of an MSE than it would be in a tactical assessment. It must be stressed that Atlantis was never intended to replace traditional SS assessments, rather it is a policy examination tool to aid in the evaluation of situations or strategies that are beyond SS models.

OVERVIEW OF THE NEUS CONTINENTAL SHELF LARGE MARINE ECOSYSTEM

Physical Oceanography

The Northeast United States (NEUS) continental shelf large marine ecosystem (LME) stretches from the Gulf of Maine to Cape Hatteras, covering an area of 293,000 km^2 (Sherman 1991; Figure 2). The NEUS LME is composed of four major subregions: the Gulf of Maine (GoM), Georges Bank (GB), Southern New England (SNE), and Mid Atlantic Bight (MAB). While these four subregions are connected and exhibit flow of water and organisms across their boundaries (Figure 3), each has distinct geological, bathymetric, physical, chemical and biological properties. We modeled the NEUS LME at resolutions smaller than these four subregions, particularly to capture major hydrodynamic and biotic processes, but the four regions are well known and defined. Below we provide a description of the major oceanographic and physical features of each of these regions.

The circulation of the NEUS LME can be generally characterized as being from the northeast to the southwest. Water from the Scotian Shelf and Northeast Channel enters the GoM and travels counterclockwise. A portion leaves the GoM through the Great South Channel, but the rest moves eastward onto the northern flank of GB, creating a clockwise circulation there. This circulation results in some of the water being retained on GB while the rest continues southwestward into the SNE and MAB regions (Figure 3). Tidal forcing plays a large role in the physical dynamics of the system, allowing the shallower regions of GB to remain well mixed even when deeper portions of GB and the GoM are well stratified (Drinkwater and Mountain 1997).

The Gulf of Maine

The Gulf of Maine is a large (79,000 km^2) marine basin located along the northeastern United States and Maritime Canada (Figure 2). It is approximately 350 km long by 200 km in width and averages about 160 m in depth (Uchupi and Austin 1987). This area comprises Northwest Atlantic Fisheries Organization (NAFO) management area 5Y. It is bounded to the northeast by Nova Scotia and New Brunswick, to the west by the states of Maine, New Hampshire, and Massachusetts, to the southwest by Cape Cod, and to the south and southeast by Georges Bank (Figure 2, 5). The region contains three deep basins: Georges, Jordan, and

Wilkinson, ranging from 200-400 m in depth (Uchupi and Austin 1987). Circulation patterns in these basins are generally clockwise, but the overall pattern in the Gulf is from east to west with the entry of slope water through the Northeast Channel, exiting to the southwest through the Great South Channel (Figure 3). Bottom sediments in the GoM are mostly silt to mud with a rocky coastline bordering the states (Poppe et al. 1989). Sea surface temperature ranges from 2-5ºC during winter and can be as high as 20ºC during summer (Mountain and Holzworth 1989; Taylor and Bascunan 2001). Bottom temperatures remain relatively cool year round, ranging between 4-6ºC (Mountain and Holzworth 1989; Taylor and Bascunan 2001). The movement of deep ocean slope water into the Gulf of Maine through the Northeast Channel carries a steady supply of nutrients, but summer stratification interrupts the nutrient cycle (Schlitz and Cohen 1984). Occasionally, nutrient-poor Labrador Shelf water is transported from the north by an intense negative North Atlantic Oscillation (NAO) anomaly, and recently, fresh water from the Gulf of St. Lawrence and Arctic melting has made incursions into the region (Townsend et al. 2004).

Georges Bank

Georges Bank, a relatively large (44,000 km^2) submerged marine plateau, is an extension of the continental shelf along the eastern United States that thrusts out into the northwest Atlantic ocean in a northeasterly direction (Figure 2). It is approximately 250 km long by 125 km in width and is relatively shallow, averaging about 80 m in depth (Uchupi and Austin 1987). This area comprises NAFO management area 5Ze. The living and mineral resources of this diverse region are administered jointly by Canada and the USA, in accordance with a decision by the world court in 1984 (Backus 1987). It is bounded to the east by Nova Scotia, to the northeast by the Northeast Channel, to the north by the Gulf of Maine, to the west-southwest by the Great South Channel, and to the south by the shelf slope and Gulf Stream (Figure 2, 5). Sediments on Georges Bank are diverse, ranging from silt to large boulders, but much of the area is composed of sand and cobble (Uchupi and Austin 1987; Poppe et al. 1989). Surface temperatures during the winter average between 2-5ºC and reach up to 20ºC during the late summer (Flagg 1987). Bottom temperatures are relatively cool during winter at 3-5ºC, but because of mixing they reach a low of roughly 5ºC on the shallow part of the Bank (Flagg 1987; Mountain and Holzworth 1989; Taylor and Bascunan 2001). Nutrients are plentiful because of its unique location, with offshore upwelling along the shelf-slope break and movements of slope water into the Gulf of Maine through the Northeast Channel (Townsend et al. 2004). Gulf of Maine waters to the north are a steady source of annual nutrients and vigorous tidal mixing promotes nutrient recycling via resuspension of bottom waters from the shallow portion of the Bank (Schlitz and Cohen 1984; Franks and Chen 2001). Georges Bank is highly productive, and because of the generally clockwise pattern of its currents (Butman 1987), nutrients and plankton are concentrated and retained on this relatively shallow plateau (Drinkwater and Mountain 1997; Cohen et al. 1982; Fogarty and Murawski 1998). During periods of stratification the nutrient cycle can be temporarily interrupted, but this occurs seasonally and only in localized areas (Drinkwater and Mountain 1997).

Southern New England

Southern New England (SNE) extends from Hudson Canyon to Great South Channel and is a transitional region between the Mid Atlantic Bight (MAB) and Georges Bank (GB) (Figure 2). This area comprises NAFO management area 5Zw and 6A. Freshwater enters SNE from the

Hudson River, Long Island Sound, Narragansett Bay, and numerous small coastal watersheds, but the volume is much less than what enters the MAB from the Chesapeake and Delaware Bays (NOAA 1990). Salinity is low nearshore and increases toward the shelf break. Temperature is homogeneous in fall and winter but is highly stratified in spring and summer (Mountain 2003). Tidal forcing in SNE occurs much less frequently than on GB (Chen et al. 2001), and the dominant low-frequency flow is southwestward from GB to the MAB (Chapman et al. 1986). The area of shallow water (<30 m) in SNE is proportionally less than in MAB with the area of deeper water (60-100 m) proportionally greater. The average depth of SNE is about 70 m. Most of the SNE shelf is covered with sand, but as a result of the deeper water and relatively low currents, there is a greater proportion of area covered by silt and clay on SNE compared with the MAB (Poppe et al. 1989; Hastings et al. 2000).

Mid Atlantic Bight

The Mid Atlantic Bight (MAB) is the only north-south longshelf ecosystem of the four NEUS LME regions. It is bounded in the north by the Hudson Canyon, and in the south by eastward facing coasts of New Jersey, Delaware, Maryland, Virginia, and North Carolina (Figure 2). The continental shelf is ~ 200 km wide in the New York Bight and gradually narrows south of New Jersey to ~ 30 km off Cape Hatteras. This area comprises NAFO management area 6BC. The ecosystem includes major estuaries, namely the Hudson-Raritan River, Delaware River estuary, Chesapeake Bay, and Pamlico Sound, and many smaller estuaries that effect hydraulics and productivity. The shelf has a mean depth of 58 m and is gently sloping except where drowned river valleys incise it.

MAB shelf water characteristics are variable at a wide range of scales because the system lies in the middle latitudes at the confluence of the northward flowing Gulf Stream and southward flowing colder fresher waters derived from the Labrador Current (Chapman and Beardsley 1989). Atmospheric conditions push water derived from the Labrador Current as far south as the New York Bight (Loder et al. 1998). Gulf Stream meanders, and its rings impinge on the shelf primarily in the southern MAB. Salinities on the shelf are <34 psu and variable as a result of inputs of fresher water from estuaries and the Gulf of Maine. Strong surface fronts are formed by buoyant water off major estuaries and along the 50-m isobath (Ullman and Cornillon 2001; Castelao et al. 2008). Seasonal heating and freshwater inputs produce strong vertical stratification from late spring through fall. Surface waters are warm during summer, but subsurface "Cold Pool" water (≤8ºC) derived from winter tidal mixing in the Gulf of Maine and Nantucket Shoals flows southwest primarily along the 50- to 80-m isobaths. The "Cold Pool" is persistent north of the Hudson Shelf Valley but extends as far south as Cape Hatteras in the spring (Houghton et al. 1982; Bignami and Hopkins 2003).

Southward flowing water from the Gulf of Maine is estimated to supply ~ 50% of nitrogen available in the MAB. Major estuaries supply ~ 20%, while ~ 30% is advected from the deep ocean along the shelf break (Fennel et al. 2006).

Biology

The NEUS LME is a highly productive ecosystem (~350 – 400 g C m^{-2} yr^{-1}) which has supported numerous significant commercial fisheries for centuries (Sissenwine et al. 1984). There are large regional differences in primary production in the NEUS. The most obvious pattern is the general onshore-offshore decrease in primary production. The other obvious pattern is a general increase in primary production from north to south. At a scale smaller than the regional ecosystems, there are areas of higher productivity including GB, inshore MAB, SNE, and northwestern Gulf of Maine.

Although open in an oceanic sense, of particular interest for the NEUS LME is Georges Bank, which is highly productive (Cohen et al. 1982; Fogarty and Murawski 1998) and, as has been noted, has a high degree of nutrient recycling (Franks and Chen 2001; Schlitz and Cohen 1984). Its clockwise flow concentrates nutrients and plankton (Drinkwater and Mountain 1997; Franks and Chen 2001; Ryan et al. 2001). While Georges Bank exhibits a well-mixed tidal current zone, it is only stratified in localized, generally shallower regions and is influenced by both warmer, more saline slope waters influenced by the Gulf Stream and the GoM's colder water sources (Bisagni 2000; Drinkwater and Mountain 1997). Georges Bank has remained remarkably consistent in its overall primary production, with production and standing stock biomass of phytoplankton staying relatively stable over the past few decades (O'Reilly and Zetlin 1998).

The NEUS LME supports a large number of tropical, subtropical, temperate, and subarctic species (Collette and Klein-McPhee 2002). The varied oceanography of the northwest Atlantic continental shelf helps to create a complex ecosystem. Georges Bank can be characterized by cold temperate fauna, but further to the south along the shelf, the large seasonal temperature fluctuations support migratory species of both cold and warm temperate fauna. Three quarters of the 250 shore fish species south of Georges Bank reported by Briggs (1974) are considered to be warm temperate or tropical in nature and either migrated from south of Cape Hatteras or were brought north by the Gulf Stream; whereas many of the species in the Gulf of Maine are considered colder-water species. Compared to other ecosystems at similar latitudes, the number of species and the interactions between these species are quite high (Figure 4; Link 1999, 2002).

The energy flow in the NEUS LME has been characterized throughout various points in time (Link et al. 2008a, 2008b). Clarke's (1946) Georges Bank food web provided an integrated perspective for oceanographers, marine ecologists, and fisheries scientists on the classical grazing food chain (diatoms-zooplankton-fish). Then in the early 1970s, biological oceanographers developed a new paradigm for the ocean food web that emphasized the large pools of dissolved and particulate organic carbon (POC) and its utilization by microbes, with the microbial loop becoming an important focus of models constructed by this research community. In the 1980s, (Cohen et al. 1982; Sissenwine et al. 1984) models of Georges Bank incorporated some of these ideas on the potential role of detritus (nonliving POC) and bacteria in supporting the benthic food chain. The primary focus in the pelagic water column remained on the grazing food chain, using better estimates of primary production. Since then, more contemporary models have been developed to support an ecosystem approach to management and have begun reconnecting the conceptual approaches of oceanographers and fishery scientists on understanding how the ocean food web operates. The future challenge is to better integrate these perspectives. The various views and perspectives of the food web have all had varying degrees of species aggregation and emphasis of differing processes, yet the fundamental core observations remain; this is a productive ecosystem, environmental factors influence lower trophic levels, fishing pressures and related factors influence upper trophic levels, and most of the "action" is at intermediate trophic levels (Link et al. 2006, 2008b, 2009; Steele et al. 2007). Of most interest with respect to living marine resource issues has been what the fish community has done over the past several decades.

Major declines in groundfish and flounders occurred in the Gulf of Maine during 1961-1972 (Brown et al. 1976; Gabriel 1992). Analyses by Clark and Brown (1977) suggested a decline in overall biomass of over 40% in this region during 1963-1974, with declines in groundfish and flounders ranging from 25-85%, depending on species. Cluster analysis classified the Gulf of Maine as a separate zoogeographic region when the entire shelf area from Cape Hatteras to Nova Scotia was analyzed (Gabriel 1992).

Brown et al. (1976) documented the severe decline in biomass on Georges Bank following several years of intense fishery exploitation during the International Commission for Northwest Atlantic Fisheries (ICNAF) era of 1961-1972. Subsequent analyses showed a decline of over 37% in the overall fish biomass of the Georges Bank region during 1963-1974 (Clark and Brown 1977; Gabriel 1992). Additional analyses measured fishing effort at over 900,000 hrs/yr fished in the early 1960s and showed that catch per unit effort (CPUE) had declined dramatically during 1960-1987 on Georges Bank (Mayo et al 1992). Other studies focused on the relative persistence of assemblages in the region, documenting declines and recovery of several important groups of fishes (Overholtz and Tyler 1985; Gabriel 1992). Overholtz and Tyler (1985) showed that several groups of fishes consistently occupied spatial regions (depth zones) of the Bank over time, while Gabriel (1992) showed similarly persistent trends as well as an extension of these groups to the south and west into Southern New England.

Brown et al. (1976) showed that many of the major groundfish, flounders, and other species declined in the Southern New England region during 1961-1972. Clark and Brown (1977) suggested that this decline in biomass averaged 52% during 1963-1974 with a range of 6-99% for declining species. For example, cod (*Gadus morhua*) declined 53%, haddock (*Melanogrammus aeglefinus*) 99%, silver hake (*Merluccius bilinearis*) 43%, winter flounder (*Pseudopleuronectes americanus*) 55%, and goosefish (*Lophius americanus*) 18% during this time period. In other studies of the area, Southern New England tended to be aligned with Georges Bank in analyses that attempted to identify regions of persistent species composition during 1967-1988 (Gabriel 1992).

The overall decline in biomass in the Mid Atlantic area was apparently the largest of the four NEUS LME ecosystems with an estimated average 74% decrease occurring during 1963-1974 (Clark and Brown 1977; Gabriel 1992). Declines ranging from 8-99% were recorded for several species of principal groundfish, flounders, and other groundfish. For example, silver hake declined 78%, yellowtail flounder (*Limanda ferruginea*) 99%, summer flounder (*Paralichthys dentatus*) 72%, winter flounder 93%, and goosefish 29% (Clark and Brown 1977). Other studies of this region suggest that the southern Mid Atlantic Bight should be classified as a unique region based on the composition of fishes in the area (Gabriel 1992).

Fisheries

As noted, the NEUS LME has supported significant commercial fisheries for multiple centuries (Sissenwine et al. 1984; Rosenberg et al. 2005). Although there are regional differences, overall the response of the northwest Atlantic ecosystems to five hundred years of exploitation has been very similar. The recent history of the component fish stocks has exhibited the classic cycles of excessive effort, stock declines, and iterations thereof until the point of sequential stock depletion (Fogarty and Murawski 1998; Murawski et al. 1997; Serchuk et al. 1994; Link 2007). The major fishery-related events over the past several decades can be characterized loosely as the following sequence. First there was an increase in small pelagic catches by foreign fleets, then a continued increase in demersal groundfish catches, followed by a precipitous decline in small pelagic stocks. Next followed a decline of some groundfish stocks, then an effective cessation of the small pelagic fisheries (and expulsion of foreign fleets), then a continual series of overfishing on an ever-increasing array of groundfish. After that there was an increase in elasmobranch stocks, the beginnings of an increase in small pelagic stocks, and then an establishment of elasmobranch fisheries and an increase in benthic invertebrate fisheries and stocks. Finally, the persistence of groundfish stocks at moderate to low levels in the south and the collapse of groundfish in the north was observed, followed by the persistence of groundfish fisheries at suboptimal yields, then the decline of elasmobranch stocks and subsequently their fisheries, after which there was the effective explosion of small pelagic stocks to what are now record highs (Serchuk et al. 1994; Murawski and Fogarty 1998; Link and Brodziak 2002; Overholtz 2002). In response to these changes, fisheries have diversified to exploit a broad range of invertebrates and nontraditional species.

The first fisheries management measures of any consequence were imposed by ICNAF, whose initial objective was to use science to maintain maximum sustainable catch (Halliday and Pinhorn 2002). To begin with, in the 1950s ICNAF imposed mesh size regulations in the trawl fishery, increasing from 73 mm to 114 mm. ICNAF then introduced catch control in the 1960s. However, when distant water fleets started operating in the northwest Atlantic, with the consequent depletion of fish stocks, there was a clear need for direct controls on fishing. The establishment of the "two-tier" quota management system in 1974 by ICNAF (ICNAF 1974; Murawski et al. 1997) provided the nucleus for recovery of depleted stocks. This approach included explicit recognition and allowance for bycatch, discarding practices, and interspecific interactions (Brown et al. 1976) and as such was a strong precursor to an ecosystem approach, but unfortunately the two-tier system was never fully implemented.

In the United States, quota-based management was maintained under the early years of extended jurisdiction (i.e., after the 1976 Magnuson-Stevens Act) but was replaced by more gear-specific measures (constraints on mesh size, legal size limits for fish, and short-term areal and seasonal closures) in 1982. When these measures failed to adequately protect fishery resources, more restrictive measures (including the use of large-scale year-round closures and limits to days-at-sea) were added in 1994 (Murawski et al. 1997; Fogarty and Murawski 1998). Quota-based approaches were more commonly retained in the MAB.

Meanwhile there have been notable changes to protected, endangered, and threatened species (PETS), with many in more critical condition than 50 years ago (Waring et al. 2004). Additionally, shifts in nontargeted fauna such as some benthos and nontargeted fishes occurred (Link and Brodziak 2002), with some actually persisting at relatively stable levels or even increasing (Link and Brodziak 2002; Link 2007). This all occurred while the regional dynamics in physiochemical conditions were also changing as noted above, particularly long-term warming (Taylor and Bascunan 2001) and NAO shifts (Drinkwater et al. 2003).

MODELING APPROACH AND METHODOLOGY

As noted above, Atlantis is a revised version of Bay Model 2 (BM2) (Fulton 2001; Fulton et al. 2004a, 2004c, 2004d). Atlantis is a deterministic model that tracks the nutrient (nitrogen and silicate) flow through the main biological groups found in temperate marine ecosystems, along with three detritus groups (labile detritus, refractory detritus, and carrion). The invertebrate and primary producer groups are simulated with aggregate biomass pools, while the vertebrates are represented with age-structured models. Again, the primary processes considered in Atlantis are consumption, production, waste production, migration, predation, recruitment, habitat dependency, and natural and fishing mortality. A summary of the chief assumptions is given in Table 1.

We ran our simulations for 50 years. The runs started in 1964 and ended in 2014. The differential equations for the system dynamics are solved with a simple adaptive forward difference method, with an overall time step of 12 hours.

MODEL STRUCTURE

Boxes, Habitat, Physics, and Chemistry

Hydrodynamics

The hydrographic submodel included in Atlantis (and BM2 before it) is a transport model, modified from the model originally developed for the Port Phillip Bay Integrated Model (PPBIM) by Murray and Parslow (1999) and Walker (1999). Horizontally, it partitions the modeled area into discrete polygons (Figure 5). The size of each polygon reflects the spatial homogeneity in the physical variables represented in the model: depth, seabed type (reef or flat), canyon coverage, porosity, bottom stress, erosion rate, salinity, light, and temperature. Vertically, Atlantis partitions the modeled area into multiple layers (up to 5 water column layers, an epibenthic layer, and a sediment layer (Figure 5)). The fluxes driving the transport model are either derived from a spatially and temporally finely resolved, three-dimensional nonlinear, variable-density hydrodynamic model (Walker 1999) or from satellite data. The model is also driven by seasonal variation in irradiance and temperature, as well as by nutrient inputs from point sources, atmospheric deposition of dissolved inorganic nitrogen (DIN), and exchanges with an oceanic boundary boxes. If the deepest water column box contacts the sediments, a sediment chemistry submodel resolves nutrient remineralization and oxygen exchange. Otherwise, the bottom of the deepest water column box is treated as an open boundary.

The only physical processes in Atlantis that differ from those in the PPBIM and BM2 (detailed in Murray and Parslow 1999; Walker 1999) are bioturbation, bioirrigation, and the calculation of the light attenuation coefficient.

The light attenuation coefficient is from Fulton (2001) and is formulated as:

$$n = n_{\mathrm{w}} + n_{\mathrm{DON}} \cdot DON + n_{\mathrm{D}} \cdot \left(DL + DR\right) + n_{\mathrm{P}} \cdot \sum_{\mathrm{i=PX}} PX + n_{\mathrm{susp}} \cdot SUSP \qquad \text{(EQ. 1)}$$

with n_{w} the background extinction coefficient, n_{DON} the contribution from dissolved organic nitrogen (*DON*), n_{D} the contribution from labile detritus (*DL*) and refractory detritus (*DR*), n_{P} the contribution from phytoplankton (*PX*), and n_{susp} the contribution from suspended sediments (*SUSP*).

The equations for bioirrigation are as detailed in Walker (1999) for PPBIM. In Atlantis these equations are tied to the dynamical sediment fauna via an “enhancement” term similar to that of the European Regional Seas Ecosystem Model (ERSEM I, Ebenhöh et al. 1997).

Atlantis uses explicit sediment layers and thus can approximate particulate diffusion, expulsion (whereby material at depth is moved to the surface), and exchange with the surface by sediment transfers between appropriate layers of the model. Only those particulate components (tracers) that are allowed in the sediments and are not macrobenthos (sediment grains, settled phytoplankton, microphytobenthos, meiobenthos, detritus, and sediment bacteria) can be acted upon by bioturbation. The tracer concentration in the ith sediment layer ($BX_i(t)$) at the end of a time step is formulated as:

$$BX_i(t+\Delta t) = \frac{BX_{i+1}(t)\cdot f_{i+1} + BX_{i-1}(t)\cdot f_{i-1} + BX_i(t)\cdot z_i - 2\cdot BX_i(t)\cdot f_i - BX_i(t)\cdot c_i - BX_i(t)\cdot w_i + BX_0(t)\cdot w_0}{f_{i+1} + f_{i-1} + z_i - 2f_i - c_i - w_i + w_0} \quad \text{(EQ. 2)}$$

$$f_i = \frac{\varpi\cdot\chi\cdot o\cdot\Omega_i}{z_i} \quad \text{(EQ. 3)}$$

$$c_i = \sigma\cdot\chi\cdot o\cdot\Omega_i \quad \text{(EQ. 4)}$$

$$w_i = \eta\cdot\chi\cdot o\cdot\Omega_i \quad \text{(EQ. 5)}$$

where f_i represents the thickness transferred from i by particulate diffusion, c_i is the thickness moved to the surface from layer i by expulsion, w_i is the thickness moved from layer i by exchange with surface layers, and z_i is the thickness of layer i. The thicknesses f_i, c_i, and w_i only differ in a single parameter. For the parameters they share, χ represents the base density of biological activity; o represents the modification to the baseline to reflect dynamic sediment fauna activity in the ecological submodel (calculated in much the same way as that of ERSEM (see Ebenhöh et al. 1997)); and Ω_i is the depth dependence of the mixing process (this is a simple functional form, as of PPBIM, and though usually constant, it is also possible to implement linear, parabolic, and half-Gaussian forms (Walker 1999)). The parameter which does differ in the calculation of f_i, c_i, and w_i is the base rate of each process; ϖ is the rate of particle diffusion (m^2 per Δt per unit biomass of bioturbative benthos per m^2), σ is the rate of expulsion (m per Δt per unit biomass of bioturbative benthos per m^2), and η is the rate of exchange between the surface and deeper layers (m per Δt per unit biomass of bioturbative benthos per m^2). A small amount of burial of sediments and associated detrital particles is also enabled by using a similar formulation.

The Atlantis NEUS model covers the continental shelf from the Gulf of Maine to Cape Hatteras (i.e., the NEUS LME). The area of the NEUS LME is approximately 293,000 km^2. We divided the NEUS LME into 22 dynamic regions (or polygonal "boxes"), each with up to 4 depth zones defined by bathymetric contours (Figure 5). These regions were based on the biogeography of the NEUS LME. The geomorphology of the region was used to define the model domain and polygonal spatial structure of the model, with structures representing subregional scales all explicitly resolved. Depth, substrate grain size, and biological communities were all considered in the establishment of these boxes. We also established 8 boundary boxes (or islands) representing areas outside the model domain in which most processes are not simulated (exceptions include growth, reproduction, and migration to and from the model domain boxes). Atlantis NEUS divides the water column into depth layers: one layer for nearshore regions and up to four layers (0-50 m, 50-120 m, 120-300 m, and 300+ m) for the offshore boxes. Processes can also occur at the surface layer and the epibenthic layer. These depth layers correspond to approximate depths of stratification, the major shelf areas, the maximal depths in most regions, and beyond, respectively.

The transport model, used to represent advective and diffusive transport across the region, was based on flows derived from the Hybrid Coordinate Ocean Model (HYCOM) model (served by a Live Access Server (LAS) at http://www.hycom.org/ or http://hycom.rsmas.miami.edu/). The flows across each face (side) of the Atlantis NEUS polygons were calculated by interpolating the model velocity fields to a set of evenly spaced locations along the faces. These fields were then used to compute the perpendicular velocity at each depth level at each location (i.e., each depth layer interface at each of the evenly spaced points along the face). The base flows are then the sum of the contributions (with each contribution provided by the product of velocity and face area) for all above-seafloor portions of the face. These base flows are finally corrected for hyperdiffusion within boxes. To do this an east-west/north-south decomposition of flows was performed per box, with each of the pair components scaled down by the dimensions of the polygon in that orientation (i.e., the east-west flows were divided by the east-west width of the box and similarly for the north-south flows). A conservative tracer was then used to check flows through the system, with box specific flow tuning scalars used to remove any remaining hyperdiffusion effects. If this combined correction is not made, then flows within the larger boxes would be overstated by orders of magnitude, as once in a box any tracer is assumed to be equally accessible throughout the box which artificially inflates flows; this effect is removed by the correction. This is a fairly basic approach to correcting for hyperdiffusion, but to date no better method has been found for box models of this type (particle tracking also suffers from hyperdiffusion, and inverse methods are often ill-posed on such large domains). Where the vertical fluxes remained underestimated, values for upwelling were adapted from Lough and Manning (2001; c.f. Loder and Wright 1985; Loder et al. 1998).

Water column properties (temperature and salinity) were also obtained from the HYCOM model (using the hindcast weekly time series from the Marine Environment and Security for the European Area (MERSEA) North Atlantic Class 1 data products). These properties were calculated by first vertically interpolating the HYCOM profiles to a set of depths that were uniformly distributed within each of the Atlantis NEUS model depth layers. The final temperature and salinity values were a simple average over all grid points within each polygon.

Sediment Chemistry, Mineralization, and Associated Detrital Processing

Here we describe mineralization of detritus, sediment chemistry, and the dynamics of bacteria associated with those processes, particularly as they relate to the processing of various forms of detritus. Use of a compound effect of enhanced bioturbation (δ_{e}) and porosity (*POR*) is based on observations by Alongi (1998) and the relationship detailed by Blackburn (1987). Coupled with equations (EQ. 45) to (EQ. 48), the utilization of labile detritus by aerobic or anaerobic bacteria is given by:

$$P_{\mathrm{DL,XB}} = G_{\mathrm{XB}} \cdot \frac{\rho_{\mathrm{XB}} \cdot \tau_{\mathrm{XB,DL}} \cdot DL}{XB \cdot \varepsilon_{\mathrm{XB,DL}}} \qquad \text{(EQ. 6)}$$

where $\varepsilon_{\mathrm{XB,DL}}$ is the assimilation efficiency of the bacteria (*XB*, both aerobic bacteria [*AEB*] and anaerobic bacteria [*ANB*]) on labile detritus (*DL*).

The uptake of refractory detritus (*DR*) is calculated similarly. The natural mortality term (M_{XB}) is as for the other invertebrates, but the term representing predation losses of bacteria to predator group *i* ($P_{XB,i}$) is given by:

$$P_{\mathrm{XB,i}} = P_{\mathrm{DL,i}} \cdot \rho_{XB} \cdot \tau_{\mathrm{XB,DL}} + P_{\mathrm{DR,i}} \cdot \rho_{\mathrm{XB}} \cdot \tau_{\mathrm{XB,DR}} \quad \text{(EQ. 7)}$$

The waste handling equations for bacteria are also different from those for other invertebrates since wastes are channelled into *DON*, not *DL*. All of the equations for anaerobic bacteria are as for *XB*, except that any δ_{O2} factors in the equations (EQ. 46 and 47) are replaced by (1-δ_{O2}). Adopting these equations for the attached bacteria made it easier to identify a method of introducing dynamic flexibility to the empirical nitrification-denitrification model proposed by Murray and Parslow (1999) for PPBIM.

A more interactive form of the processes governing nitrification and denitrification was integrated into Atlantis. The empirical sediment chemistry model used in PPBIM (Murray and Parslow 1999) is linked directly to the activities of sediment bacteria and infauna. The amount of ammonia (NH) produced by the remineralization of DON (R_{DON}) is handled as in PPBIM, that is:

$$R_{\mathrm{DON}} = \Phi \cdot DON \cdot POR \quad \text{(EQ. 8)}$$

where Φ is the temperature-dependent rate of breakdown for *DON* (set at 0.00176 d^{-1}, Murray pers. com.). In Atlantis the production of the remainder of the ammonia is dependent upon the activity of sediment dwelling fauna and flora. Thus, the total ammonia available for nitrification and denitrification (R_{NET}) is:

$$R_{\mathrm{NET}} = \boldsymbol{max}\left(0\, , R_{\mathrm{DON}} + E_{\mathrm{AEB}} + E_{\mathrm{ANB}} + \xi \cdot \left(E_{\mathrm{OB}} + E_{\mathrm{BD}}\right) - P_{\mathrm{NH,MB}}\right) \quad \text{(EQ. 9)}$$

where $P_{\mathrm{NH,MB}}$ is the uptake of *NH* by microphytobenthos (*MB*) (see equations for autotrophs; EQ. 42-44), E_{XX} is the ammonia released by *XX,* and ξ is the fraction of the excreted *NH* by infauna that contributes available nitrogen for nitrification and denitrification (set to 0.95). The form of E_{XX} for *OB* and *BD* is of the general form given for heterotrophs in Fulton (2001), Fulton et al. (2004a, 2004b, 2004c, 2004d) and Murray and Parslow (1999), but that for *AEB* and *ANB* is slightly different and is given by:

$$E_{\mathrm{XB}} = P_{\mathrm{DL,XB}} \cdot \left(1 - \varepsilon_{\mathrm{XB,DL}}\right) + P_{\mathrm{DR,XB}} \cdot \left(1 - \varepsilon_{\mathrm{XB,DR}}\right) + M_{\mathrm{XB}} - W_{\mathrm{DON}} - W_{\mathrm{DR}} \quad \text{(EQ. 10)}$$

where E_{XB} is the release of *NH* by *XB*, $\varepsilon_{XB,DX}$ is the efficiency of *XB* on the detritus fraction *DX*, and the production of *DON* (W_{DON}) and *DR* (W_{DR}) are calculated as follows:

$$W_{\mathrm{DON}} = \left(P_{\mathrm{DL,XB}} \cdot \left(1 - \varepsilon_{\mathrm{XB,DL}}\right) + P_{\mathrm{DR,XB}} \cdot \left(1 - \varepsilon_{\mathrm{XB,DR}}\right) + M_{\mathrm{XB}} \cdot \varphi_{\mathrm{XB}}\right) \cdot \mathrm{f}_{\mathrm{XB,DON}} \quad \text{(EQ. 11)}$$

$$W_{\mathrm{DR}} = \left(P_{\mathrm{DL,XB}} \cdot \left(1 - \varepsilon_{\mathrm{XB,DL}}\right) + M_{\mathrm{XB}} \cdot \varphi_{\mathrm{XB}}\right) \cdot \mathrm{f}_{\mathrm{XB,DR}} \quad \text{(EQ. 12)}$$

where φ_{XB} indicates the fraction of the losses of *XB* from natural mortality that are not released as *NH* and $f_{XB,DX}$ is the fraction of the products of growth inefficiency and mortality directed to the detritus fraction *DX*. By using equation (EQ. 9), the processes of nitrification and denitrification were completed by using the form of the empirical model of Murray and Parslow (1999), giving nitrification (S_{NIT}) as:

$$S_{\mathrm{NIT}} = R_{\mathrm{NET}} \cdot \theta_{\mathrm{DMAX}} \cdot \boldsymbol{max}\left(0\,,1 - \frac{R_{\mathrm{NET}} \cdot \gamma_{\mathrm{SED}}}{\mathrm{r0}}\right) \quad \text{(EQ. 13)}$$

and denitrification (S_{DENIT}) as:

$$S_{\mathrm{DENIT}} = S_{\mathrm{NIT}} \cdot \boldsymbol{min}\left(1\,,\frac{R_{\mathrm{NET}} \cdot \gamma_{\mathrm{SED}}}{\theta_{\mathrm{rD}}}\right) \quad \text{(EQ. 14)}$$

where θ_{DMAX} is the maximum rate of denitrification (set at 0.25, Murray pers. com.), θ_{r0} is the temperature-dependent minimum rate of respiration that supports nitrification (set at 200, Murray and Parslow 1999), and θ_{rD} (set at 10, Murray and Parslow 1999) is the peak of the nitrification-denitrification curve (as defined by Murray and Parslow 1999). This general form is adopted from PPBIM because of its demonstrated performance and robustness (Murray and Parslow 1999; Fulton 2001).

The equations for oxygen are modified from Walker (1999) because of the more interactive representation of the sediment processes, with oxygen dynamics governed by:

$$O2_{\mathrm{bw,t+1}} = \frac{\left(O2_{\mathrm{bw,t}} \cdot VOL_{\mathrm{bw}} + O2_{\mathrm{sed,t}} \cdot VOL_{\mathrm{por}}\right)}{VOL_{\mathrm{bw}} + VOL_{\mathrm{por}}} + e^{-\phi_{irr}\cdot\left(\frac{1}{VOL_{\mathrm{bw}}}+\frac{1}{VOL_{\mathrm{por}}}\right)} \cdot \left(O2_{\mathrm{bw,t}} - \frac{\left(O2_{\mathrm{bw,t}} \cdot VOL_{\mathrm{bw}} + O2_{\mathrm{sed,t}} \cdot VOL_{\mathrm{por}}\right)}{VOL_{\mathrm{bw}} + VOL_{\mathrm{por}}}\right) \quad \text{(EQ. 15)}$$

$$O2_{\mathrm{sed,t+1}} = O2_{\mathrm{sed,t}} - \frac{VOL_{\mathrm{bw}}}{VOL_{\mathrm{por}}} \cdot \left(O2_{\mathrm{bw},t+1} - O2_{\mathrm{bw,t}}\right) \quad \text{(EQ. 16)}$$

where ϕ_{irr} is the exchange rate from irrigation, $O2_{\mathrm{SED,t}}$ is the concentration of oxygen in the sediment at time t, $O2_{\mathrm{bw,t}}$ is the concentration of oxygen in the bottom water at time *t*, VOL_{bw} is the volume of the bottom water layer, and the porewater volume above the oxygen horizon is given by:

$$VOL_{\mathrm{por}} = POR \cdot \frac{\gamma_{\mathrm{o2}} \cdot \chi_{\mathrm{cell}}}{VOL_{\mathrm{sed}}} \quad \text{(EQ. 17)}$$

with VOL_{sed} being the volume of the entire sediment layer, γ_{o2} is the oxygen depth, and χ_{cell} is the area of the cell.

In the case of Atlantis NEUS, we have used the default parameters for these processes, only changing them slightly in the biophysical phase of calibration (noted below) to ensure adequate recycling of nutrients.

Nutrients

Atlantis can track several nutrients. We note all of these here, but Atlantis mainly tracks nitrogen as a common currency. The rate of change for NH in the water column is:

$$\frac{d(NH_{\mathrm{w}})}{dt} = -\sum_{\mathrm{i=PX_w}} P_{\mathrm{NH_w,i}} - P_{\mathrm{NH_w,MB_w}} - P_{\mathrm{NH_w,MA}} - P_{\mathrm{NH_w,PFB}} + \sum_{\mathrm{i=CX_w,BF}} E_{\mathrm{i}} + \sum_{\mathrm{i=FX}} E_{\mathrm{i}} + \sum_{\substack{\mathrm{i=pelagic}\\ \mathrm{bacteria}}} E_{\mathrm{i}} - S_{\mathrm{NIT,PAB}} + R_{\mathrm{NET,w}}$$

(EQ. 18)

and in the sediment:

(EQ. 19)

$$\frac{d(NH_{\mathrm{sed}})}{dt} = R_{\mathrm{NET,sed}} - S_{\mathrm{NIT,sed}} - P_{\mathrm{NH_{sed},MB_{sed}}} - P_{\mathrm{NH_{sed},SG}} + \sum_{\mathrm{i \neq BF,CX_w}} E_{\mathrm{i}}$$

where PNH,XX is the uptake of NH by the autotroph XX, ECX is the production of NH by the consumer CX, SNIT,XB is the amount of NH lost from nitrification by the bacteria XB, and RNET is the amount of NH produced by denitrification. These and similar, subsequent equations are presented as rate coefficients (as noted) which are multiplied by the state variables (in this case, NH) that results in the derivative changes noted.

The rate of change for nitrate (*NO*) in the water column is:

$$\frac{d(NO_{\mathrm{w}})}{dt} = -\sum_{\mathrm{i=PX_w}} P_{\mathrm{NO_w,i}} - P_{\mathrm{NO_w,MB_w}} - P_{\mathrm{NO_w,MA}} + S_{\mathrm{NIT,PAB}}$$

(EQ. 20)

and in the sediment:

$$\frac{d(NO_{\mathrm{sed}})}{dt} = S_{\mathrm{NIT,sed}} - S_{\mathrm{DENIT,sed}} - P_{\mathrm{NO_{sed},MB_{sed}}} - P_{\mathrm{NO_{sed},SG}}$$

(EQ. 21)

The rate of change of dissolved silicate (*Si*) in the water column is:

$$\frac{d(Si_{\mathrm{w}})}{dt} = R_{\mathrm{DSisol,w}} - \sum_{\mathrm{i=PL_w,MB_w}} P_{\mathrm{Si_w,i}}$$

(EQ. 22)

and the rate of change of detrital silica (*DSi*) in the water column is given by:

$$\frac{d(DSi_{\mathrm{w}})}{dt} = \mathrm{X_{SiN}}\left(\sum_{\mathrm{i=PL_w,MB_w}}\left(M_{\mathrm{lys,i}} + \sum_{\mathrm{j=CX_w}} P_{\mathrm{i,j}}\right)\right) - R_{\mathrm{DSisol,w}}$$

(EQ. 23)

where XSiN is the Redfield ratio of silicon and nitrogen (set at 3.0 (Murray and Parslow 1999)) and RDSisol is the amount of detrital silica remineralized. Note that the equations for Sised and DSised are as for (EQ. 22) and (EQ. 23) except that CXsed is used in the place of CXw and MB is the only PX present in the sediment that uses Si.

The rate of change for dissolved oxygen (*O2*) in the water column is:

$$\frac{d(O2_{\mathrm{w}})}{dt} = \mathrm{X_{ON}}\left(\sum_{\mathrm{i=PX_w}} G_{\mathrm{i}} + G_{\mathrm{MB_w}} + G_{\mathrm{MA}} + \frac{G_{\mathrm{SG}}}{2} - \sum_{\substack{\mathrm{i \neq infauna,}\\ \mathrm{MZ,BG}}} E_{\mathrm{i}} - \sum_{\mathrm{i=FX}} E_{\mathrm{i}} - \sum_{\substack{\mathrm{i=pelagic}\\ \mathrm{bacteria}}} E_{\mathrm{i}} - R_{\mathrm{DON,w}}\right)$$

(EQ. 24)

and in the sediment:

$$\frac{d(O2_{\mathrm{sed}})}{dt} = \mathrm{X}_{\mathrm{ON}}\left(G_{\mathrm{MB}_{\mathrm{sed}}} + \frac{G_{\mathrm{SG}}}{2} - \sum_{\substack{\mathrm{i=infauna,}\\ \mathrm{MZ,BG}}} E_{\mathrm{i}} - R_{\mathrm{DON,sed}}\right)$$

(EQ. 25)

where XON is the Redfield ratio of oxygen and nitrogen (set at 16.0 (Murray and Parslow 1999)) and RDON is the DON lost through remineralization.

The rate of change of DON in the water column is:

$$\frac{d(DON_{\mathrm{w}})}{dt} = W_{\mathrm{DON,w}} - R_{\mathrm{DON,w}} - P_{\mathrm{DON,PFB}}$$

(EQ. 26)

and in the sediment:

$$\frac{d(DON_{\mathrm{sed}})}{dt} = W_{\mathrm{DON,sed}} - R_{\mathrm{DON,sed}}$$

(EQ. 27)

where WDON is the DON produced by bacteria, RDON is the DON lost through remineralization, and PDON,PFB is the DON taken up by pelagic free bacteria (PFB).

The rate of change of DL in the water column is:

$$\frac{d(DL_{\mathrm{w}})}{dt} = \sum_{\mathrm{i=CX_w}} W_{\mathrm{DL_w,i}} + \sum_{\mathrm{i=FX}} W_{\mathrm{DL_w,i}} + \sum_{\substack{\mathrm{i=pelagic}\\ \mathrm{bacteria}}} W_{\mathrm{DL_w,i}} + \sum_{\mathrm{i=PX_w}} M_{\mathrm{lys,i}} + M_{\mathrm{lys,MB_w}} + M_{\mathrm{MA}} - P_{\mathrm{DL_w,PAB}} - P_{\mathrm{DL_w,BF}}$$

(EQ. 28)

and in the sediment:

$$\frac{d(DL_{\mathrm{sed}})}{dt} = \sum_{\mathrm{i=PX_{sed}}} M_{\mathrm{nat,i}} + M_{\mathrm{nat,MB_{sed}}} + M_{\mathrm{lys,MB_{sed}}} + M_{\mathrm{SG}} + \sum_{\mathrm{i=infauna}} \left(W_{\mathrm{DL,i}} - P_{\mathrm{DL_{sed},i}}\right) + \sum_{\mathrm{i=epifauna}} \left(W_{\mathrm{DL,i}} - P_{\mathrm{DL_{sed},i}}\right) - \sum_{\mathrm{i=FX}} P_{\mathrm{DL_{sed},i}}$$

(EQ. 29)

where WDL,CX is the amount of DL in the waste products from consumer CX and PDL,CX is the DL consumed by CX.

The rate of change of *DR* in the water column is:

$$\frac{d(DR_{\mathrm{w}})}{dt} = \sum_{\mathrm{i=FX}} W_{\mathrm{DR_w,i}} - \sum_{\mathrm{i=CX_w}} P_{\mathrm{DR_w,i}} - P_{\mathrm{DR_w,PAB}} - J_{\mathrm{DR}} \qquad \text{(EQ. 30)}$$

and in the sediment:

$$\frac{d(DR_{\mathrm{sed}})}{dt} = \sum_{\mathrm{i=infauna}} W_{\mathrm{DR_{sed},i}} - \sum_{\mathrm{i=infauna}} P_{\mathrm{DR_{sed},i}} + J_{\mathrm{DR}} \qquad \text{(EQ. 31)}$$

where $W_{\mathrm{DR,CX}}$ is the *DR* in the wastes of consumer *CX,* $P_{DR,CX}$ is the amount of detritus consumed by *CX*, infauna includes sediment bacteria, and J_{DR} is the amount of *DR* transferred from the water column to sediment pool from the feeding activities of the benthic filter feeders.

In the case of Atlantis NEUS, we have used the default parameters for these processes, only changing them slightly in the biophysical phase of calibration (noted below) to ensure adequate recycling of nutrients. In terms of informing initial values of these nutrients, we used online data sources (University of Maine's Gulf of Maine Region Nutrient and Hydrographic Database, http://grampus.umeoce.maine.edu/nutrients/; D. Townsend, pers. comm.; Townsend 1991; Townsend et al. 2004) and Marine Resources Monitoring, Assessment and Prediction Program (MARMAP) nutrient data (J. O'Reilly, pers. comm.).

Biology

We simulate the dynamics of 49 functional groups, using nitrogen as the common currency between groups (Table 2, Appendix A). Living flora and fauna make up 43 of these functional groups, while detrital pools make up the other 6. There are 24 vertebrate groups and 14 invertebrate groups. Within the vertebrate groups, there are 5 charismatic groups (birds and mammals). Individual species within each functional group have similar diet compositions, life histories, and distributions.

Groups

Primary Producers and Bacteria

The Atlantis model tracks primary producer abundance (mg N/m^3) per region, as an aggregated biomass pool. Growth is limited by nutrient, light, and space availability. Biomass is lost to grazing (i.e., predation), lysis, and mortality (linear and quadratic). Linear mortality represents density-independent mortality in addition to the mortality sources explicitly modeled. Quadratic mortality represents density-dependent mortality.

The rate of change for a standard water column primary producer (PX) is :

$$\frac{d(PX_{\mathrm{w}})}{dt} = G_{\mathrm{PX_w}} - M_{\mathrm{lys,PX_w}} - \sum_{\substack{\mathrm{i=predator} \\ \mathrm{groups}}} P_{\mathrm{PX_w,i}} \qquad \text{(EQ. 32)}$$

$$\frac{d(PX_{sed})}{dt} = -M_{nat,PX_{sed}} \tag{EQ. 33}$$

where G_{PX} stands for the growth of PX, $M_{lys,PX}$ is the loss of PX through lysis, $M_{nat,PX}$ is the natural mortality losses of PX when in the sediments, and $P_{PX,I}$ are the losses of PX through predation. The equations for the benthic primary producers are slightly different. The rate of change of microphytobenthos is given by:

$$\frac{d(MB_w)}{dt} = G_{MB_w} - M_{lys,MB_w} - \sum_{\substack{i=\text{water predator}\\ \text{groups}}} P_{MB_w,i} \tag{EQ. 34}$$

$$\frac{d(MB_{sed})}{dt} = G_{MB_{sed}} - M_{nat,MB_{sed}} - \sum_{\substack{i=\text{sed predator}\\ \text{groups}}} P_{MB_{sed},i} \tag{EQ. 35}$$

The general formulation for the dynamics of aerobic attached bacteria (where XB stands for Pelagic Attached Bacteria (PAB) or sediment bound AEB) is:

$$\frac{d(XB)}{dt} = G_{XB} - M_{XB} - \sum_{\substack{i=\text{consumer}\\ \text{groups}}} P_{XB,i} \tag{EQ. 36}$$

Growth of primary producers is formulated as:

$$G_{PX} = \mu_{PX} \cdot \delta_{irr} \cdot \delta_{N} \cdot \delta_{space} \cdot PX \tag{EQ. 37}$$

where μ_{PX} is the maximum growth rate and δ_X are limitation coefficients. The nutrient limitation factor for nitrogen is given by:

$$\delta_N = \frac{DIN}{\kappa_{N,PX} + DIN} \tag{EQ. 38}$$

(where $DIN=NH+NO$). For those primary producers that are also limited by the availability of Si, nutrient limitation is given by:

$$\delta_N = \boldsymbol{min}\left(\frac{DIN}{\kappa_{N,PX} + DIN}, \frac{Si}{\kappa_{Si,PX} + Si}\right) \tag{EQ. 39}$$

Light limitation is given by:

$$\delta_{irr} = \boldsymbol{min}\left(\frac{IRR}{\kappa_{irr,PX}}, 1\right) \tag{EQ. 40}$$

where IRR = photosynthetic available radiation at the depth of the primary producer (Wm^{-2}). In

EQ. 38- 40, κ represents the half saturation constants for the respective processes. Space limitation is as follows:

$$\delta_{space} = 1 - \frac{PX}{\theta_{\mathrm{PXmax}} \cdot \delta_{substrate} \cdot \delta_{habdegrad}} \qquad \text{(EQ. 41)}$$

where $\delta_{substrate}$ is the proportion of the available space that is of the correct depth and substrate type to support this type of primary producer and δhabdegrad is the scalar for local habitat degradation scenarios. The terms δsubstrate and δhabdegrad only apply to macrophytes (which are not utilized in the NEUS application of the model).

The nutrient uptake functions for the primary producer PX are given by using the above formulations for growth and nutrient limitation:

$$P_{\mathrm{NH,PX}} = G_{\mathrm{PX}} \cdot \frac{NH}{\kappa_{\mathrm{NH,PX}} + NH} \cdot \frac{\kappa_{\mathrm{NH,PX}} + DIN}{DIN} \qquad \text{(EQ. 42)}$$

$$P_{\mathrm{NO,PX}} = G_{\mathrm{PX}} \cdot \frac{NO}{DIN} \cdot \frac{\kappa_{\mathrm{NH,PX}}}{\kappa_{\mathrm{NH,PX}} + NH} \qquad \text{(EQ. 43)}$$

where $\kappa_{\mathrm{NH,PX}}$ is the half saturation constant for the uptake of *NH*. In addition, for *PL* and *MB* there is the uptake of *Si* as follows:

$$P_{\mathrm{Si,PX}} = \mathrm{X}_{\mathrm{SiN}} \cdot G_{\mathrm{PX}} \qquad \text{(EQ. 44)}$$

The growth of the bacteria (G_{XB}) is given by:

$$G_{\mathrm{XB}} = \mu_{\mathrm{XB}} \cdot XB \cdot \boldsymbol{max}\left(0\,\boldsymbol{,}\left(1 - \rho_{\mathrm{XB}}\right)^{\psi}\right) \qquad \text{(EQ. 45)}$$

and

$$\rho_{\mathrm{XB}} = \frac{XB}{\left(\tau_{\mathrm{DL,XB}} \cdot DL + \tau_{\mathrm{DR,XB}} \cdot DR\right) \cdot \delta_{\mathrm{O2}} \cdot \delta_{\mathrm{stim}}} \qquad \text{(EQ. 46)}$$

with μ_{XB} representing the maximum temperature-dependent daily growth rate for the group *XB*. *XB* is the current pool of bacteria, and *DL* and *DR* are the labile and refractory detrital pools (all in mg N m^{-3}); $\tau_{\mathrm{DL,\,XB}}$ and $\tau_{\mathrm{DR,\,XB}}$ represent the maximum possible biomass of *XB* per biomass of that grade of detritus; ψ is the exponent dictating the reduction in growth as the bacterial pool approaches its maximum attainable levels (set to 3); and δ_{O2} is the oxygen limitation factor, which is given by:

$$\delta_{O2} = \begin{cases} \dfrac{\gamma_{O2}}{\gamma_{O2} + \gamma_{XB}}, & \text{XB benthic} \\ 1, & \text{otherwise} \end{cases} \quad \text{(EQ. 47)}$$

where γ_{XB} is the half oxygen mortality depth for *XB* and the oxygen horizon (γ_{O2}) is given by:

$$\gamma_{O2} = \frac{2 \cdot O2_{sed} \cdot \gamma_{sed}}{O2_{bw}} \quad \text{(EQ. 48)}$$

with $O2_{sed}$ the concentration of oxygen in the sediments, $O2_{bw}$ the concentration in the bottom water, and γ_{sed} the depth of the sediment layer considered in the model. Finally δ_{stim} indicates the degree of stimulation of the bacteria by bioturbation, and it is calculated as follows:

$$\delta_{stim} = \begin{cases} \dfrac{\delta_{te} \cdot 250 \cdot (POR\text{-}0.225)}{193.75}, & \text{XB benthic} \\ 1, & \text{otherwise} \end{cases} \quad \text{(EQ. 49)}$$

The rate of change for standard water column (*w*) primary producer (*PX*) is

(EQ. 50)

$$\frac{d(PX_w)}{dt} = G_{PXw} - M_{lys,PX} - M_{lin} - M_{quad} - \sum_{i=predatorgroups} P_{PXw,i}$$

$$G_{PX} = \mu_{PX} \cdot \delta_{irr} \cdot \delta_{N} \cdot \delta_{space} \cdot PX \quad \text{(EQ. 51)}$$

where G_{PX} is the growth of *PX*, $M_{lys,PX}$ is loss of *PX* through lysis, M_{lin} and M_{quad} are losses from linear and quadratic mortality, $P_{PX,I}$ are losses of *PX* through predation, μ_{PX} is the maximum growth rate, δ_{irr} is light limitation, δ_{N} is nutrient limitation, and δ_{space} is space limitation. Appendix A contains values for μ, M_{lin} and M_{quad} for our model; M_{lys} was set to 0.

In the case of Atlantis NEUS, we had three primary producer (PP) groups (Table 2); these include diatoms, dinoflagellates (combined with diatoms for large PP), and picophytoplankton (small PP). The data to initialize and parameterize these organisms came from the results of our EMAX efforts (Link et al. 2006, 2008b) as informed from satellite imagery (J. O'Reilly pers. comm.; Thomas et al. 2003) and associated sampling (MARMAP; J. O'Reilly, pers. comm.; O'Reilly and Zetlin 1998).

Invertebrates

The Atlantis model tracks invertebrate abundance (mg N/m^3) per region, as an aggregated biomass pool within each spatial box, based on growth, predation, and linear and quadratic mortality. Quadratic mortality in this case represents density-dependent effects (predation, disease) that are not explicitly modeled; the ultimate effect of which is to impose a reasonable carrying capacity. In general we attempted to set linear and quadratic mortality to 0 when possible (Table A.2). We have attempted to explicitly include all significant ecological components; as such there was limited need to call upon these extra mortality terms, which represent ecological components not treated explicitly.

The rate of change for a standard invertebrate consumer (*CX*) is:

$$\frac{d(CX)}{dt} = G_{\mathrm{CX}} - M_{\mathrm{CX}} - \sum_{\substack{\mathrm{i=predator}\\ \mathrm{groups}}} P_{\mathrm{CX,i}} - F_{\mathrm{CX}} \qquad \text{(EQ. 52)}$$

where F_{CX} stands for losses through fishing on this group. Invertebrate consumers are restricted to existing only in the water column, as epibenthos on the sediment surface, or in the sediment pool. They cannot be dynamically active or mobile in two or three of these pools. Epibenthos can feed in the sediments and watercolumn, but do not actively move into those locations.

The growth of *CX* is given by:

$$G_{\mathrm{CX}} = \left(\varepsilon_{\mathrm{CX}} \cdot \sum_{\substack{\mathrm{i=living}\\ \mathrm{prey}}} P_{\mathrm{i,CX}} + \sum_{\mathrm{j=DL,DR}} \left(P_{\mathrm{j,CX}} \cdot \varepsilon_{\mathrm{CX,j}} \right) \right) \cdot \delta_{\mathrm{space}} \cdot \delta_{\mathrm{o2}} \qquad \text{(EQ. 53)}$$

with $\varepsilon_{\mathrm{CX}}$ the growth efficiency of *CX* when feeding on live prey, $\varepsilon_{\mathrm{CX,j}}$ the efficiency when feeding on detritus (*DL* treated separately to *DR*), and δ terms as limiting factors. Space limitation given by:

$$\delta_{space} = \begin{cases} 1 - \dfrac{\delta_{substrate} \cdot \delta_{habdegrad} \cdot \left(CX - \theta_{\mathrm{CXlow}}\right) \cdot \frac{\left(CX - \theta_{\mathrm{CXlow}}\right)}{CX - \theta_{\mathrm{CXlow}} + \kappa_{\mathrm{CXsat}}}}{\delta_{substrate} \cdot \delta_{habdegrad} \cdot \left(CX - \theta_{\mathrm{CXlow}}\right) \cdot \frac{\left(CX - \theta_{\mathrm{CXlow}}\right)}{CX - \theta_{\mathrm{CXlow}} + \kappa_{\mathrm{CXsat}}} + \kappa_{\mathrm{CXthresh}}} & , \ CX = \mathrm{BF} \text{ and } CX > \theta_{CXlow} \\ 1 & , \ \text{otherwise} \end{cases} \qquad \text{(EQ. 54)}$$

where θ_{CXmax} is the maximum biomass per area allowed for *CX*, θ_{CXlow} is the crowding lower threshold, κ_{CXsat} is the crowding half saturation level, $\kappa_{\mathrm{CXthresh}}$ is the crowding threshold (this formulation is based on that of the ERSEM II [Blackford 1997]), $\delta_{substrate}$ is the proportion of the available space that is of the correct depth and substrate type to support this type of primary producer, and $\delta_{habdegrad}$ is the scalar for local habitat degradation scenarios.

Oxygen limitation is given by:

$$\delta_{\mathrm{o2}} = \begin{cases} \dfrac{\gamma_{\mathrm{o2}}}{\gamma_{\mathrm{o2}} + \kappa_{\mathrm{CX,Mo2}}} & , \text{if epifauna or infauna} \\ 1 & , \text{if pelagic} \end{cases} \qquad \text{(EQ. 55)}$$

where γ_{o2} is the depth of the oxygen horizon and $\kappa_{CX,Mo2}$ is the half oxygen mortality depth.

In the case of Atlantis NEUS, we had 14 invertebrate groups (Table 2). Data to initialize and parameterize these organisms largely came from the Energy Modeling and Analysis eXercise (EMAX; Link et al. 2006, 2008b) and associated surveys (Azarovitz 1981; NEFC 1988; NEFSC unpubl. data). We had 2 stages (juvenile and adults) for squids and shrimp. Details of these parameters and initial values are found in Tables A.2-A.11, A.13-18, and A.20.

Vertebrates

The Atlantis model supports multiple age classes for vertebrates. Our parameterization utilizes 10 age classes (Appendix A). It is possible for each vertebrate to have different time spans for corresponding age classes because the age classes represent different phases in the vertebrate's lifecycle. For some groups the age classes might be one year each, while for other longer lived groups it might be a decade or more for each class. This has been determined to be a computationally efficient way of representing vertebrates with drastically different longevities within a common model framework. The lifespan of each vertebrate is detailed in Table A.1, and the duration of each of the 10 age classes for a given vertebrate is 10% of its lifespan**.**

The following are the rates of change for a vertebrate group (FX):

$$\frac{d\left(FX_{\mathrm{i,s}}\right)}{dt} = G_{\mathrm{FX_{i,s}}} \tag{EQ. 56}$$

$$\frac{d\left(FX_{\mathrm{i,r}}\right)}{dt} = G_{\mathrm{FX_{i,r}}} \tag{EQ. 57}$$

$$\frac{d\left(FX_{\mathrm{i,d}}\right)}{dt} = T_{\mathrm{IMM,FX_i}} - T_{\mathrm{EM,FX_i}} - M_{\mathrm{FX_i}} - \sum_{\substack{\mathrm{j=predator}\\ \mathrm{groups}}} P_{\mathrm{FX,j}} - F_{\mathrm{FX_i}} \tag{EQ. 58}$$

where the subscript *s* stands for structural weight (skeletal and other material that can not be reabsorbed), *r* for reserve weight (fats and other tissues that can be broken down when food is scarce), and *d* for density. The subscript *i* represents age class or life phase; there is one equation for each age class included. The *T* terms represent the movement of vertebrates into ($T_{\mathrm{IMM,Fxi}}$) and out of ($T_{EM,\mathrm{Fxi}}$) the cell. In addition there are short-term spawning and recruitment events which effect the various *FX* pools. At the same point each year (the exact day dependent on the vertebrate and with a window of +/- 14 days), the vertebrates reproduce, and the materials required to do this are removed from the reserve weight of *FX*. At which point the proportion of the age class growing into the next age class is then noted (also, if in a scenario with external adult stocks, then the oldest age class in the system leaves the system at this time). Sometime later (the exact period dependent on the group) the recruits settle out, and their weights and density are assigned to the youngest age class.

The amount of reserve weight (mg N per individual) that is used up during spawning is given by:

$$s_{\mathrm{FX}_i} = \begin{cases} \mathrm{U}_{\mathrm{FX}_i} \cdot \boldsymbol{max}\left(0, \left(\mathrm{Z}_{\mathrm{FX}} \cdot \left(1 + \mathrm{X}_{\mathrm{RS}}\right) \cdot FX_{\mathrm{i,s}} - \mathrm{Y}_{\mathrm{FX}}\right)\right) & , \; FX_{\mathrm{i,s}} + FX_{\mathrm{i,r}} > \left(1 + X_{\mathrm{RS}}\right) \cdot FX_{\mathrm{i,s}} \\ \mathrm{U}_{\mathrm{FX}_i} \cdot \boldsymbol{max}\left(0, \left(\begin{matrix} \mathrm{Z}_{\mathrm{FX}} \cdot \left(1 + \mathrm{X}_{\mathrm{RS}}\right) \cdot FX_{\mathrm{i,s}} + \left(FX_{\mathrm{i,s}} + FX_{\mathrm{i,r}}\right) \\ - \mathrm{Y}_{\mathrm{FX}} - \left(1 + \mathrm{X}_{\mathrm{RS}}\right) \cdot FX_{\mathrm{i,s}} \end{matrix}\right)\right) & , \; FX_{\mathrm{i,s}} + FX_{\mathrm{i,r}} < \left(1 + X_{\mathrm{RS}}\right) \cdot FX_{\mathrm{i,s}} \end{cases}$$

(EQ. 59)

where U_{Fxi} is the proportion of age class i that is reproductively mature, Z_{FX} is the fraction of the weight of FX used in spawning, Y_{FX} is the spawning function constant, and X_{RS} is the ratio of structural to reserve weight in well-fed vertebrates.

There are many formulations for recruitment. Constant recruitment is given as:

$$b_{tj} = J_t \quad \text{(EQ. 60)}$$

where J_t is element t of the recruitment vector (constant spatially and temporally). More commonly a Beverton-Holt recruitment function was implemented by using the following formulation:

$$b_{tj} = \frac{\left(\dfrac{\alpha \cdot L_{tj}}{\beta + L_{tj}}\right)}{t_x} \quad \text{(EQ. 61)}$$

where α is the Beverton-Holt α for the vertebrate group; β is the Beverton-Holt β for the vertebrate group (i.e., the density independent and density dependent parameters, respectively); t_x is total length of recruit period; and the biomass of the offspring of vertebrate group FX in cell j at time t (L_{tj}) is determined as follows:

$$L_{\mathrm{tj}} = \sum_{\mathrm{i=age\ class}} s_{\mathrm{FX_i}} \cdot FX_{\mathrm{i,d}} \cdot \left(1 + \omega_{recruit} \cdot \delta[t]\right)$$

(EQ. 62)

where s_{FXi} is the spawn from age class i of FX, $\omega_{recruit}$ is the scalar for episodic recruitment, and $\delta[t]$ is an impulse function, which is only nonzero when time t is a multiple of the period of the recruitment pulses.

The growth for each vertebrate group is calculated by equation of the same form as EQ. 53, but per age class of each vertebrate. The result is then apportioned to structural and reserve weight increases such that:

$$G_{\mathrm{FX_{i,s}}} = \Lambda \cdot G_{\mathrm{FX_i}} \quad \text{(EQ. 63)}$$

$$G_{\mathrm{FX_{i,r}}} = \left(1 - \Lambda\right) \cdot G_{\mathrm{FX_i}} \quad \text{(EQ. 64)}$$

where

$$\Lambda = \begin{cases} \dfrac{\dfrac{1}{X_{RS}} + X_{pR,FX} \cdot \left(\dfrac{FX_{i,r}}{X_{RS} \cdot FX_{i,s}} \right)}{\dfrac{1}{X_{RS}} + \left(\dfrac{FX_{i,r}}{X_{RS} \cdot FX_{i,s}} \right)} & \text{, if} > 0 \text{ and } G_{FX_i} > 0 \\ = 0 & \text{, otherwise} \end{cases} \qquad \text{(EQ. 65)}$$

and where X_{RS} is the maximum ratio of reserve to structural weight *FX* can have and $X_{pR,FX}$ is the relative degree to which *FX* replenishes reserves rather than undergoing structural growth when underweight.

The foraging term (across all consumers *CX*, including vertebrates) is given by:

$$P_{prey,CX} = \frac{CX \cdot k_{CX} \cdot p_{prey,CX} \cdot \delta_{refuge} \cdot prey}{1 + k_{CX} \cdot \dfrac{\varepsilon_{CX} \cdot \left(\sum\limits_{\substack{j=\text{live prey}\\ \text{groups}}} p_{j,CX} \cdot j \right) + \varepsilon_{CX,DL} \cdot p_{DL,CX} + \varepsilon_{CX,DR} \cdot p_{DR,CX}}{\mu_{CX}}} \qquad \text{(EQ. 66)}$$

where "prey" is the group being consumed by *CX*, k_{cx} is the clearance rate of *CX*, and $p_{prey,CX}$ is preference (or availability) of that prey for the predator *CX*. This last parameter is similar to the "vulnerability" parameters in ECOSIM (Christensen et al. 2000) and represents the fact that the entire prey population will not be available to the predators at any one time (for instance some may be hiding). The availability of the food is further modified by δ_{refuge} if the group is dependent on biogenic habitat refuges or size refuges (if they are physically outside the gape range of their vertebrate predators), or if the spatial range of the predator and prey do not completely overlap (and so explicit spatial refuges exist). If the group is dependent on biogenic habitat, then δ_{refuge} is given by:

$$\delta_{refuge} = \exp\left(-\kappa_{cover} \cdot d_{cover} + \theta_{cover}\right) + \frac{1}{\theta_{cover}} \qquad \text{(EQ. 67)}$$

where -κ_{cover} is the refuge magnitude coefficient, θ_{cover} is the habitat steepness coefficient, and d_{cover} is the relative cover in the cell for the prey, which is calculated by:

$$d_{cover} = \left(\delta_{substrate,habdegrad} \cdot \rho_{substrate} + \sum_j \rho_{biogenic,j} \right) \cdot \left(1 + \rho_{canyon}\right) \qquad \text{(EQ. 68)}$$

where $\delta_{substrate,habdegrad}$ is degradation in the physical habitat from coastal development (e.g., reefs broken up), $\rho_{substrate}$ is the proportion of the cell covered with suitable substrate types, $\rho_{substrate,j}$ is the proportion of the cell covered by biogenic habitat defining group *j*, and ρ_{canyon} is the proportion of the cell covered by canyons (which is treated as an enhancement factor here as they are known to concentrate production, but their absence does not prevent the establishment and growth of the groups [Alan Williams *pers. com.*]).

For each age class and each spatial cell, the model tracks the number of individuals and their average structural weight and reserve weight. Growth and abundance are functions of recruitment, predation, consumption, and linear and quadratic mortality. We tracked abundance, biomass, weight-at-age, and condition (reserve weight/structural weight) of each group through time in each box and for the entire model domain. We evaluated model performance based upon how closely model-predicted values for biomass matched expected values.

In the case of Atlantis NEUS, we had 24 vertebrate groups (Table 2). Data to initialize and parameterize these organisms largely came from the Northeast Fisheries Science Center (NEFSC) bottom trawl survey (Azarovitz 1981; NEFC 1988), length-weight studies (Wigley et al. 2003), and EMAX (Link et al. 2006, 2008b). Additionally, assessments for those species that have been formally assessed were used to inform and initialize the model (http://www.nefsc.noaa.gov/sos/, http://www.nefsc.noaa.gov/nefsc/saw/). As noted above, these functional groups were partitioned into 10 stages that were fractions of the total life span. Details of these parameters and initial values are found in Tables A.1, A.3-12, and A.14-19.

For each of the functional forms, we chose to model recruitment as the standard Beverton-Holt stock-recruitment function. Details of our parameterization of the Beverton-Holt relationship are in Appendix A, Table A.1. The exception was for the seabird group, which used a fixed recruitment.

Major Biological Processes

Predation

Atlantis bases growth of vertebrate functional groups on von Bertalanffy growth parameters that vary with consumption. We chose a Holling type II functional response for predation by most functional groups, except marine mammals and seabirds, which we parameterized as type III functional responses. Previous work by Fulton et al (2004c) suggests that this type (II) is simple to parameterize yet is as effective as other representations given the nature of questions to be asked of strategic models. Alternative feeding functional responses exist within Atlantis, and future sensitivity analyses could consider their use when evaluating potential model structural sensitivity. Our implementation of the Holling type II functional response is:

(EQ. 69)

$$P_{ij} = \frac{B_i \cdot a_{ij} \cdot B_j \cdot C_j}{1 + \frac{C_j}{g_j}\left(E_j^l \cdot \sum_{k=1}^{l} B_k \cdot a_{k,j} + E_j^f \cdot \sum_{h=1}^{f} B_h \cdot a_{h,j} + E_j^d \cdot \sum_{x=1}^{d} B_x \cdot a_{x,j} + E_j^r \cdot \sum_{y=1}^{r} B_y \cdot a_{y,j} \right)}$$

where P_{ij} is the proportion of prey i in the diet of predator j; B_i is the biomass of prey i; and B_j is the biomass of predator j; a_{ij} is the availability of prey i to predator j (Tables A.14-A.18); C_j is the maximum ingestion rate of predator j; g_j is the maximum growth rate of predator j; $E^l{}_j$ is the assimilation efficiency of predator j on live food (the l superscript); $E^f{}_j$ is the assimilation efficiency of predator j on seagrass, macroalgae, or phytoplankton; $E^d{}_j$ is the assimilation efficiency of predator j on labile detritus; and $E^r{}_j$ is the assimilation efficiency of predator j on refractory detritus. The sums in the denominator are simply the sums of each of the available food biomasses (animal prey, primary producers, labile detritus, and refractory detritus). Values for prey availability parameters (a) are detailed in Tables A.14 – A.18. Values for g are contained in Tables A.12 and A.13, and values for C are contained in Tables A.19 and A.20.

The initial diets from the NEFSC food habits database and EMAX (Link et al. 2006) exercise were used to initialize the availability terms for the NEUS LME functional groups. A more formal means of calculating availability was developed as we iterated through the initialization of the model (R. Gamble, unpubl. data) but was largely used to provide context for our initial estimates.

Migration and Movement

The default vertebrate movement (in terms of the density *d* of vertebrate group *FX*, age class *i*, in cell *j*) is given by:

$$FX_{i,d,j} = \begin{cases} FX_{i,tot} \cdot \left(\vartheta \cdot \left(FX^{D}_{j,qrt+1,FX} - FX^{D}_{j,qrt,FX}\right) + FX^{D}_{j,qrt,FX}\right), & \text{qrt} < 4 \\ FX_{i,tot} \cdot \left(\vartheta \cdot \left(FX^{D}_{j,1,FX} - FX^{D}_{j,qrt,FX}\right) + FX^{D}_{j,qrt,FX}\right), & \text{qrt} = 4 \end{cases} \quad \text{(EQ. 70)}$$

where $FX_{\mathrm{i,tot}}$ is the total number of *FX* in age class *i* in the entire system (i.e., the sum over all cells), ϑ is the proportion of the current quarter of the year which has already passed, and $FX^{D}_{j,qrt,FX}$ is the proportion of the population of *FX* found in cell *j* in the *qrt* quarter of the year.

For the forage and density dependent vertebrate movement scheme, the following formulation is used:

$$G_{\mathrm{FX,i,j,potential}} = \begin{cases} g_{\mathrm{roc\_mult}} \cdot G_{\mathrm{FX,i,j}}, & G_{\mathrm{FX,i,j}} > g_{\mathrm{thesh}} \\ \dfrac{G_{\mathrm{FX,i,j}}}{g_{\mathrm{roc\_mult}}}, & \text{otherwise} \end{cases} \quad \text{(EQ. 71)}$$

$$G_{\mathrm{FX,i,tot}} = \sum_{\mathrm{all\ j}} G_{\mathrm{FX,i,j}} \quad \text{(EQ. 72)}$$

$$FX^{D}_{i,d,j,t} = \frac{G_{\mathrm{FX,i,j,potential}} \cdot d_{\mathrm{cov}er} \cdot \delta_{depth} \cdot FX^{D}_{i,d,j,t,other}}{G_{\mathrm{FX,i,tot}}} \quad \text{(EQ. 73)}$$

$$FX_{\mathrm{i,d,j}} = FX_{\mathrm{i,tot}} \cdot \left(FX_{i,vel} \cdot \left(FX^{D}_{i,d,j,t} - FX^{D}_{i,d,j,t-1}\right) + FX^{D}_{i,d,j,t-1}\right) \quad \text{(EQ. 74)}$$

where $G_{\mathrm{FX,i,j,potential}}$ is a measure of the potential attractiveness of the cell *j* based on the available forage, $G_{FX,i,\mathrm{j}}$ is calculated as of G_{CX} in EQ. 53, g_{roc_mult} is a constant reflecting how much more attractive a site with forage sufficient to support FX_i is over a site with poor food resources, g_{thresh} is the potential growth rate (as an index of the quality of the resources) where FX_i switch from finding the site desirable to undesirable, d_{cover} is the relative cover in the cell for the group FX_i (set to 1 for all groups that are not habitat dependent), and δ_{depth} is the distribution over the water column depth layers. To take into account other pressures on fish movement (such as seasonal or spawning migration), the calculation of the proportion $FX^{D}_{i,d,j,t}$ is weighted by the ideal distribution for those other migration factors, and then the final distribution is determined by interpolating between the current distribution and the ideal distribution (taking the maximum swim speed of the vertebrate into account so that individuals can not move further than they could actually swim in reality). These $FX_{i,d,j}$ values are then normalised so that their sum is one.

If a vertebrate group is site attached, then it only moves vertically at most, and if the group employs maternal care, then the movement scheme is calculated for the mothers and then applied to them and the juvenile age classes.

In the case of Atlantis NEUS, we allowed density-dependent movement of nekton, sea birds, and marine mammals between boxes. Plankton moved via advection between boxes. In general, movement transfers abundance towards neighboring boxes with higher potential growth rates. For several functional groups of vertebrates (e.g., herring, spiny dogfish, baleen whales) we forced the model with seasonal migrations. These migrations are well documented (Link et al. 2006) and represent shifts associated with changes in feeding, spawning, or similar life history events. We also initialized the model distributions of abundance and biomass for most groups as estimated from surveys (Azarovitz 1981; NEFC 1988).

Mortality

The mortality terms for both invertebrate consumers and autotrophs (see above) are in terms of lost biomass while those for vertebrates refer to the number of individuals lost. Nevertheless, the general form of the equations is the same even though the units of the coefficients obviously differ between the vertebrates and other groups. The natural mortality term for group XX is given by

$$M_{\mathrm{XX}} = \mathrm{m}_{\mathrm{lin,XX}} \cdot XX + \mathrm{m}_{\mathrm{quad,XX}} \cdot XX^2 + (1-\delta_{\mathrm{o2}}) \cdot \mathrm{m}_{\mathrm{o2,XX}} \cdot XX + \mathrm{m}_{\mathrm{special,XX}} \cdot XX$$

(EQ. 75)

where $m_{lin,XX}$ is the coefficient of linear mortality for XX, $m_{quad,XX}$ is the coefficient of quadratic mortality for the group XX, $m_{O2,XX}$ is the coefficient of oxygen dependent mortality, and $m_{special,XX}$ is the special (additional) loss rate for XX. This rate of “special” mortality is usually set to zero, except in the following cases:

$$\mathrm{m}_{\mathrm{special,MA}} = STRESS \cdot \mathrm{m}_{\mathrm{STRESS}} \qquad \text{(EQ. 76)}$$

$$\mathrm{m}_{\mathrm{special,SG}} = DIN \cdot \mathrm{m}_{\mathrm{DIN}} \qquad \text{(EQ. 77)}$$

where m_{STRESS} and m_{DIN} are the coefficient of mortality from mechanical stress and fouling by epiphytes, respectively. Lastly, for vertebrate pools:

$$\mathrm{m}_{\mathrm{special,FX_i}} = \begin{cases} \dfrac{\mathrm{m}_{\mathrm{starve,FX}} \cdot \theta_{\mathrm{starve}} \cdot (1+\mathrm{X}_{\mathrm{RS}}) \cdot \mathrm{FX}_{\mathrm{i,s}} - (\mathrm{FX}_{\mathrm{i,s}} + \mathrm{FX}_{\mathrm{i,r}})}{(1+\mathrm{X}_{\mathrm{RS}}) \cdot \mathrm{FX}_{\mathrm{i,s}}}, & \text{if} > 0 \\ = 0, & \text{otherwise} \end{cases}$$

(EQ. 78)

with $m_{starve,FX}$ is the threshold ratio of reserve to structural weight at which death by starvation is likely. While all the groups in the model had a linear mortality term to represent disease and other, nonpredation sources of mortality, the vertebrates and higher trophic level zooplankton and benthic groups suffered mortality described by a quadratic term. Only benthic consumers had oxygen dependent mortality, the vertebrate groups had special mortality as shown above, and m_{top} is only applied to the vertebrate groups.

The final loss term is applied to the microscopic primary producers only, and it represents lysis. The loss rate of a primary producer (*PX*) to lysis is formulated as follows:

$$M_{\mathrm{lys,PX}} = \frac{\mathrm{m}_{\mathrm{lys,PX}} \cdot PX}{\delta_{\mathrm{N}} + 0.1} \qquad \text{(EQ. 79)}$$

with $m_{lys,PX}$ as the rate of lysis and δ_N is the nutrient limitation term from EQ 51.

In the case of Atlantis NEUS, we used the standard loss terms and their default values for these groups (with minimal special mortality and no oxygen dependent mortality) as modified via predation and fishing rates. The one caveat is that we did alter the quadratic mortality term for some of the invertebrates (particularly shrimp and cephalopods) in preliminary calibrations.

Waste

Waste production by invertebrate and vertebrate consumers is handled in the same way, but in the case of vertebrates the mortality term has to be converted from a density to a biomass before being used in the following equations. The production of labile detritus (*DL*) by consumer group *XX* is given by:

$$W_{\mathrm{DL}} = \left(\begin{array}{l} (1-\varepsilon_{\mathrm{XX}}) \cdot \Gamma_{\mathrm{XX}} \cdot \sum\limits_{\substack{\mathrm{i=living\ prey} \\ \mathrm{group}}} P_{\mathrm{i,XX}} + (1-\varepsilon_{\mathrm{XX,DL}}) \cdot \Gamma_{\mathrm{XX,DL}} \cdot P_{\mathrm{DL,XX}} \\ + (1-\varepsilon_{\mathrm{XX,DR}}) \cdot \Gamma_{\mathrm{XX,DR}} \cdot P_{\mathrm{DR,XX}} + \varphi_{\mathrm{XX}} \cdot \mathrm{M}_{\mathrm{XX}} \end{array} \right) \cdot \mathrm{f}_{\mathrm{XX,DL}} \qquad \text{(EQ. 80)}$$

with φ_{XX} the proportion of mortality losses assigned to detritus, Γ_{XX} the proportion of the growth inefficiency of *XX* when feeding on live prey that is sent to detritus, $\Gamma_{XX,DL}$ the proportion of the growth inefficiency of *XX* when feeding on *DL* that is sent to detritus, $\Gamma_{XX,DR}$ the proportion of the growth inefficiency of *XX* when feeding on refractory detritus (*DR*) that is sent to detritus, and $\mathrm{f}_{\mathrm{XX,DL}}$ is the proportion of the total detritus produced that is of the type *DL*. The same equation is used for the production of *DR* (W_{DR}), except that the final multiplication by $f_{XX,DL}$ is replaced by multiplication by $(1-f_{XX,DL})$.

The other main waste product is excreted ammonia. The general formulation used for denoting the production of ammonia by a consumer XX (invertebrate or vertebrate) is as follows:

$$\begin{aligned} E_{\mathrm{XX}} = {} & (1-\varphi_{\mathrm{XX}}) \cdot M_{\mathrm{XX}} + (1-\varepsilon_{\mathrm{XX}}) \cdot (1-\Gamma_{\mathrm{XX}}) \cdot \sum_{\substack{\mathrm{i=living\ prey} \\ \mathrm{group}}} P_{\mathrm{i,XX}} + (1-\varepsilon_{\mathrm{XX,DL}}) \cdot (1-\Gamma_{\mathrm{XX,DL}}) \cdot P_{\mathrm{DL,XX}} \\ & + (1-\varepsilon_{\mathrm{XX,DR}}) \cdot (1-\Gamma_{\mathrm{XX,DR}}) \cdot P_{\mathrm{DR,XX}} \end{aligned} \qquad \text{(EQ. 81)}$$

In the case of Atlantis NEUS we used the default values for recycling of waste.

Fisheries

The Atlantis model includes the main types of fleets typical in most marine ecosystems. Each fleet is characterised by its target, byproduct and bycatch groups, gear type (and associated selectivity curve and habitat impacts), habitat dependency, discarding, and effort allocation submodels. The alternative fisheries submodels are detailed below after the fleets in each operating model are described. Ports are also considered in a spatial context as part of the fleet dynamics when considering distance to travel for targeted functional groups relative to their abundance.

Many different fishing mortality equations were used, depending on the scenario of interest. As an example of the general form (similar to what is below but with the group biomass replacing the $((FX_{s,i} + FX_{r,i}) \cdot FX_{d,i})$ term), the amount of a vertebrate caught at time t is given by:

$$F_{\mathrm{FX,t}} = C_{\mathrm{eff}} \cdot \left(FX_{\mathrm{s,i}} + FX_{\mathrm{r,i}}\right) \cdot FX_{\mathrm{d,i}} \cdot \delta^{FC}_{space,FX,i} \cdot \delta^{FC}_{depth,FX,i} \cdot \left(1 - FX^{FC}_{escape}\right) \qquad \text{(EQ. 82)}$$

where $\delta^{FC}_{depth,FX,i}$ is the proportion of FX_i at the depth the fishing gear is sweeping, and FX^{FC}_{escape} is the proportional escapement (either constant or size-based). The accessibility of FX_i for the fishery FC ($\delta^{FC}_{space,FX,i}$) is given by either simple percentage overlap of the habitats occupied by FX_i using:

$$\delta^{FC}_{space,FX,i} = \rho_{FC,FX} \cdot \mathrm{h}_{\mathrm{FX,i}} \qquad \text{(EQ. 83)}$$

or the distribution model developed by Ellis and Pantus (2001):

$$\delta^{FC}_{space,FX,i} = \left(1 - \min\left(1, \left(\rho_{FC,FX} \cdot \exp\left(-\frac{\eta_{FC}}{\rho_{FC,FX}} \cdot \frac{\log\left(1 + \mathrm{h}_{\mathrm{FX,i}} \cdot \eta_{pattern}\right)}{\eta_{pattern}}\right) + 1 - \rho_{FC,FX}\right)^{\eta_{patch}}\right)\right) \qquad \text{(EQ. 84)}$$

where h_{FXi} is the catchability of the age class i of FX (see EQ. 90 to EQ. 94), $\rho_{FC,FX}$ is the proportional overlap of fishery FC and vertebrate group FX, η_{FC} is the cover of the fishery, $\eta_{pattern}$ is the distribution of the fishing within the area, and η_{patch} is the number of patch types in the area. Finally, the effort applied in EQ. 82 is given by

$$C_{\mathrm{eff}} = \delta_{depth,FC} \cdot \mathrm{m}_{\mathrm{FC,FX}} \cdot \mathrm{q}_{\mathrm{FC,FX}} \cdot \mathrm{a}_{\mathrm{j,FC,FX}} \qquad \text{(EQ. 85)}$$

with $m_{FC,FX}$ the current coefficient of fishing mortality for FX by fishery FC (it can change through time as fishing pressure changes). This is expressed as the percentage of total effort (of the FC fishing fleet) concentrated in cell j if the fleet was allowed to act with effectively minimal constraints. The term $q_{FC,FX}$ is the selectivity coefficient of the gear used by fishery FC on FX, and $a_{j,FC,FX}$ is the adjustment to the final rate caused by management actions currently applied in cell j (this can also change through time). Atlantis has the ability to handle both selectivity and catchability; in the NEUS application after some initial explorations, we fixed selectivity ($q_{FC,FX}$) to 1 and allowed the catchabilities (h_{FXi}) to vary. As indicated by (EQ. 82 to EQ. 84), the realized fishing implemented for each fleet and stock combination is a variation on the simple catch equation.

The effort coefficient $\mathrm{m}_{\mathrm{FC,FX}}$ can be calculated in a number of ways, ranging from prescribed effort matrices to dynamic processes (such as basing all effort allocation on past catches or making minor modifications to long term trends of effort distribution based on recent catches in each area) and is given by one of the following equations. If effort is a temporally prescribed constant (i.e., effort per quarter is fixed), then:

$$\mathrm{m}_{\mathrm{FC,FX}} = \begin{cases} \left(\vartheta \cdot \left(\mathrm{m}^{D}_{qrt+1,FC} - \mathrm{m}^{D}_{qrt,FC}\right) + \mathrm{m}^{D}_{qrt,FC}\right), & \mathrm{qrt} < 4 \\ \left(\vartheta \cdot \left(\mathrm{m}^{D}_{1,FC} - \mathrm{m}^{D}_{qrt,FC}\right) + \mathrm{m}^{D}_{qrt,FC}\right), & \mathrm{qrt} = 4 \end{cases} \qquad \text{(EQ. 86)}$$

where ϑ is the proportion of the current quarter of the year which has already passed and $m^{D}_{j,qrt,FX}$ is the effort of fishery FC in the qrt quarter of the year. This value can be used as is (i.e., homogeneously distributed across all cells) or spatially weighted based on the catch per unit effort (CPUE) from previous time step. If the spatial distribution of the effort is prescribed rather than the temporal component, then the equation used is the same as for EQ. 86 but with $m^{D}_{qrt,FX}$ replaced with $m^{D}_{j,qrt,FX}$ the effort of fishery FC in cell j in quarter qrt.

If the effort distribution is calculated dynamically, then $m_{FC,FX}$ in cell j time t is given by:

$$\mathrm{m}_{\mathrm{FC,FX,t,j}} = \mathrm{F}_{vel} \cdot \left(\mathrm{m}_{\mathrm{eff,t,j}} - \mathrm{m}_{\mathrm{FC,FX,t\text{-}1,j}}\right) + \mathrm{m}_{\mathrm{FC,FX,t\text{-}1,j}} \qquad \text{(EQ. 87)}$$

where the ideal new distribution $m_{eff,t,j}$ given by:

$$\mathrm{m}_{\mathrm{eff,t,j}} = \frac{\omega_{FC,\max} \cdot B_{CPUE,j}}{\sum_{j} B_{CPUE,j}} \qquad \text{(EQ. 88)}$$

in which $\omega_{FC,max}$ is maximum allowable effort, $B_{CPUE,j}$ is the CPUE in the cell in the previous time step, and the velocity F_{vel} is based on the distance between cells (if CPUE based only) or the distance to the ports if using a fleet dynamics model.

EQ. 86 to EQ. 88 are used for the commercial fleets, but the recreational fishery is represented in a slightly different way:

$$\mathrm{m}_{\mathrm{eff,t,j}} = F_{recvel} \cdot \kappa_{pop} \cdot \sum_{port} N_{pop,k} \cdot \begin{cases} \left(\vartheta \cdot \left(\mathrm{m}^{D}_{j,qrt+1,rec} - \mathrm{m}^{D}_{j,qrt,rec}\right) + \mathrm{m}^{D}_{j,qrt,rec}\right), & \mathrm{qrt} < 4 \\ \left(\vartheta \cdot \left(\mathrm{m}^{D}_{j,1,rec} - \mathrm{m}^{D}_{j,qrt,rec}\right) + \mathrm{m}^{D}_{j,qrt,rec}\right), & \mathrm{qrt} = 4 \end{cases} \qquad \text{(EQ. 89)}$$

where $N_{pop,k}$ is the human population in port k, κ_{pop} is the proportion of the population that fishes recreationally, F_{recvel} is the velocity of recreational vessels based on distances to port, and $m^{D}_{j,qrt,FX}$ is the effort of the recreational fishery in cell j in quarter qrt (usually used to constrain recreational and charter boat effort to coastal cells).

If the effort displacement option (where fleets are able to refocus the locale of their effort) is being used, then the total effort for a fishery would drop by using any of these dynamic formulations (for instance either through the imposition of marine protected areas (MPAs) or declining stocks). If used, then the difference in effort for each area is redistributed to the adjacent cells with the greatest biomass of the target groups.

The selectivity coefficient $q_{FC,FX}$ may be given by one of five functions depending on the gear used by the fishery. It may be a constant proportion applied to all age classes or it may be size-based and calculated based on a normal, logistic, lognormal, or gamma distribution. The selectivity of the gear with regard to cohort i of vertebrate group FX ($q_{,i,FX}$) (similarly for the different age classes in any age structured invertebrates) is given by one of the following equations (depending on the selectivity curve of the gear). If the selectivity curve is a constant then:

$$q_{FX_i} = \kappa_{i,0} \qquad \text{(EQ. 90)}$$

If a logistic selectivity curve is used for the gear then:

$$q_{FX_i} = \left(1 + \exp\left(-\kappa_{i,1} \cdot \left(l_{i,FX} - \kappa_{i,2}\right)\right)\right)^{-1} \qquad \text{(EQ. 91)}$$

If a normal selectivity curve is used for the gear then:

$$q_{FX_i} = \exp\left(\frac{-\left(l_{i,FX} - \kappa_{i,2}\right)^2}{2 \cdot \left(\kappa_{i,1}\right)^2}\right) \qquad \text{(EQ. 92)}$$

If a lognormal selectivity curve is used for the gear then:

$$q_{FX_i} = \frac{\exp\left(-\left(\log\left(l_{i,FX}\right) - \kappa_{i,2}\right)^2 \cdot \left(2 \cdot \left(\kappa_{i,1}\right)^2\right)^{-1}\right)}{\kappa_{i,1} \cdot \sqrt{2 \cdot \pi}} \qquad \text{(EQ. 93)}$$

Finally, if a gamma selectivity curve is used for the gear then:

$$q_{FX_i} = \left(\frac{l_{i,FX}}{\kappa_{i,2}}\right)^{\kappa_{i,2} \cdot \left(0.5 \cdot \left(\sqrt{\left(\kappa_{i,2}\right)^2 + 4 \cdot \left(\kappa_{i,1}\right)^2} - \kappa_{i,2}\right)\right)^{-1}} \cdot \exp\left(\left(\kappa_{i,2} - l_{i,FX}\right) \cdot \left(0.5 \cdot \left(\sqrt{\left(\kappa_{i,2}\right)^2 + 4 \cdot \left(\kappa_{i,1}\right)^2} - \kappa_{i,2}\right)\right)^{-1}\right)$$

(EQ. 94)

where $\kappa_{t,0}$ is the selectivity constant for the fishery on the *i*th age class of vertebrate group *FX*, $\kappa_{t,1}$ is the selectivity coefficient (spread of the curve) for the fishery on the *i*th age class of vertebrate group *FX*, $\kappa_{t,2}$ is the selectivity coefficient (length at which 50% of the population is selected) for the fishery on the *i*th age class of vertebrate group *FX*, and the length ($l_{j,FX}$) of a vertebrate from cohort *i* in vertebrate group *FX* is given by:

$$l_{i,FX} = \left(\frac{\left(\kappa_{wet} \cdot X_{CN} \cdot \left(FX_{s,i} + FX_{r,i}\right)\right)}{\alpha_{w,FX} \cdot 1000}\right)^{1/\beta_{w,FX}} \qquad \text{(EQ. 95)}$$

with X_{CN} as the Redfield ratio of carbon to nitrogen, κ_{wet} is the conversion coefficient from weight to dry weight, $\alpha_{w,FX}$ is a scaling coefficient in the length-weight relationship for *FX*, and $\beta_{w,FX}$ is the exponent in the length-weight relationship. In practice the logistic or normal selectivity curves are used (unless otherwise specified for that scenario). The parameters used to specify the selectivity curve may be adjusted in response to "management decisions" made under some of the alternative management scenarios (i.e., gear restrictions can translate into changes in selectivity).

The final coefficient ($a_{j,FC,FX}$) in EQ. 85 represents management actions that influence fishing, but not by modifying the gear and its selectivity. This includes effort reduction and spatial and temporal closures or zoning. All of these approaches involve calculating or specifying the proportion of "at will" effort that is allowed under the current management strategy. If a trigger event (such as target or vulnerable stock decline) occurs, it initiates a gradual reduction in effort, which can be reversed later if the trigger recovers. The following equation is used to determine the final management coefficient ($a_{j,FC,FX}$):

$$\mathrm{a}_{\mathrm{j,FC,FX}} = \begin{cases} \left(1 - \dfrac{\left(t - t_{trigger}\right)}{t_{reduction}} \cdot (1-d)\right) \cdot \delta_{TAC} \cdot \delta_{season} \cdot \delta_{\mathrm{zone}} & \text{, if trigger event has occured} \\ \delta_{TAC} \cdot \delta_{season} \cdot \delta_{zone} & \text{, if no trigger event} \end{cases} \quad \text{(EQ. 96)}$$

where δ_{TAC} = 1 normally (but = 0 if a total allowable catch (TAC) is present and has been exceeded), δ_{season} = 1 if the fishery is not under a temporal closure, δ_{zone} = 1 if there is no spatial management in the cell (but = 0 if the cell is closed and there is no infringement), t is current time, $t_{trigger}$ is the time a trigger event occurred, $t_{reduction}$ is the time period over which the reduction in effort is to take place, and d is the final level of effort allowed relative to the original level when the effort reduction was triggered. Infringement of any of the management conditions is represented by keeping the management scalars at a user-defined level above the values they would drop to if there was no infringement. Management actions such as setting TACs or defining fishing seasons (which are scaled back as stocks decline) occur on the first time step of each year and are in place for the entire year.

Three forms of discarding were included in the model, and the specific one used in any particular case depended on the scenario under consideration. The simplest form of discarding saw a set proportion of the total catch of vertebrate *FX* by fishery *FC* discarded – the proportion of each age class actually discarded matched the percentage make-up of the catch. Another form of discarding saw a fixed proportion of all age classes discarded. The final, more realistic formulation used was based on size, where the biomass of age class *i* of *FX* discarded is given by

$$FX_i^{discarded} = \mathrm{F}_{\mathrm{FX,t}} \cdot \begin{cases} \left(1 - \rho_{illegal}\right) & l_{i,FX} < l_{legal} \\ \rho_{discard} & l_{i,FX} \geq l_{legal} \end{cases} \quad \text{(EQ. 97)}$$

and the length of the vertebrate ($l_{i,FX}$) is given by EQ. 95.

Several alternative fisheries submodels are included in the operating models. These include alternative bycatch, habitat dependency, selectivity, discarding, and effort allocation models. All of these can change through time, representing changes in fishing practices, advances in gear, alternative management strategies, and so forth.

A simple but effective representation of the many fleets in the NEUS region was achieved by using a threshold-based relative catch per unit effort (CPUE) model. For each fishery, at each active time step (some boats may only be active diurnally, while others may potentially fish at any time of the day) the relative weight (w_b) for a specific spatial box b is given by

$$w_b = \left(\frac{d_p}{D} \cdot \frac{C_b}{C}\right) \quad \text{(EQ. 98)}$$

where d_p is the relative costs of reaching that box from the home port (based on distance from home port, it is rescaled relative to the maximum costs found across the entire model domain D);

C_b is the average CPUE by that fishery in that box over the "memory period" of that fishery (this period is defined by the user and can range from a single day to the entire length of the run to that point in time; at the start of the run it is initialized with historical data); and C is the average total CPUE over the entire domain for the memory period.

The initial effort for the time step ($E_{b,t}$) applied to box b is then set at

$$E_{b,t} = E_{t-1} \cdot w_b \tag{EQ. 99}$$

This is then linearly interpolated across the spatial distribution in the last time step to produce the new distribution (to allow for vessel steaming time across particularly large spatial domains):

$$E'_{b,t} = \max\left(1.0, \frac{S}{D_{t,t-1}}\right) \cdot \left(E_{b,t} - E_{b,t-1}\right) + E_{b,t-1} \tag{EQ. 100}$$

where S is the maximum distance that can be steamed by an average boat in the fishery during the period of one timestep, and $D_{t,\,t-1}$ is the distance between the peak effort locations at time t and $t-1$.

Once a week CPUE is checked against thresholds to see if there will be investment in extra effort (or conversely a reduction in effort), with the change in effort in box b ($E_{m,b}$) defined as

$$E_{m,b} = \begin{cases} 1.0 + E_s & , C_{b,t-1} > C_U \\ 1.0 & , C_L \leq C_{b,t-1} \leq C_U \\ \min(0.0, 1.0 - E_s) & , C_{b,t-1} < C_L \end{cases} \tag{EQ. 101}$$

where E_s is the magnitude of the relative shift in weekly effort for that fishery; $C_{b,t-1}$ is the current rate of CPUE (for the previous week at that location); C_L is the lower CPUE threshold; and C_U is the upper CPUE threshold. The final realised effort (E''_b) is then given by

$$E''_b = E'_b \cdot E_{m,b} \tag{EQ. 102}$$

Note that this change will be reflected in the final total effort for this timestep, and so a change in overall dynamic effort will be realized. In cases where there are significant management changes (e.g., as happened in 1994; see below) additional forced changes can be imposed (e.g., a reduction in effort at a specific point in time to represent introduction of new restrictions or a buy-back). This then resets the total effort level, but from that point on the equations above would continue to modify the realized effort from timestep to timestep.

Fleet Definitions

In the case of Atlantis NEUS, we could have defined fleets in a number of ways. Originally each fleet was defined as a combination of gear type (14 possible gears), target groups (7 possible target groups), vessel size (5 tonnage classes, 1 shore based fishery, and 1 recreational fishery), and port location (77 discrete ports) (c.f. Hall-Arber et al. 2001). This would have resulted in 52,822 fleets. Instead, we defined the fleets used in our model as amalgamated gear and target group combinations, limiting the total number to 18 (Table 3). Each fleet was assigned target and discard functional groups which it could affect among the vertebrates and invertebrates (Table 4). Main ports were selected as the top 2 - 4 major ports in each state, representative of approximately equidistant segments along the coastline (Hall-Arber et al. 2001).

The targets and bycatch per fishery are noted, with the observation that each fleet often targeted more than one functional group. We used the times series of catches (reported as landings) and effort to initialize and calibrate the model. These data were from the NEFSC commercial fisheries database (NEFSC unpubl. data), in conjunction with national fisheries statistics (http://www.st.nmfs.noaa.gov/st1/commercial/index.html) and stock assessments (http://www.nefsc.noaa.gov/nefsc/saw/, http://www.nefsc.noaa.gov/sos/).

Three main sets of parameters were used to define the interactions of each fleet with its target and discard functional groups. The first was catchability (q) (Table A.21), the second was the fixed proportion of catch discarded for each group by a given fishery (Table A.22), and the third was a set of four effort parameters (Table A.23). Briefly, a bottom and top threshold of catch per day was set. If the catch per day for a fishery was below the bottom threshold, effort would be adjusted downward by the effort rate change parameter. If the catch per day for a fishery was above the top threshold, effort would be adjusted upward by the effort rate change parameter. The fourth effort parameter constrained max effort per day.

Additionally, we simulated the gear changes prescribed as a management action by the NEUS LME in 1994 by modifying q and effort at the time step in the model corresponding to the start of 1993 for the affected fisheries.

MODEL CALIBRATION

We present results from simulations of 50-year runs of the Atlantis NEUS model. The runs started in 1964 and ended in 2014 (with tuning data ending in 2004). Our intent was to create a “base scenario” that approximates the observed time series of surveyed or assessed biomass for each functional group included, catches on those functional groups, and effort for each fleet included. With a base scenario that approximates magnitude and pattern of these time series, we would then be able to begin to explore the qualitative effects of various fishing and management strategies on the functional groups. The full range of those scenarios is not, however, a part of this document but will be forthcoming after the structure and calibration of this Atlantis NEUS application is documented and as specific applications for such scenarios are required. Rather, here we describe the four levels of calibration needed to get to our base scenario from which future scenarios and strategies will be based.

We explored the model at four levels of calibration. These are described in detail below. At each level we attempted, as much as possible, to not alter the previously tuned parameters. Sometimes, however, new interactions were revealed when increasing levels of dynamism were modeled, necessitating changes in parameters tuned at a previous level. The goal of this tuning was to parameterize a base scenario which reasonably captured the magnitude and overall shape of the observed biomass, catch, and effort time series so that we can begin to explore qualitative effects of different management scenarios. The levels of tolerance for each level of calibration are shown in Table 5, and the results of tolerance testing for biomass, catch, and effort are presented in Tables 6-8.

Biophysical

The first level aimed to get all the ecological, physical, and chemical processes at the appropriate magnitude such that no biological group was extirpated through the model run. We do not provide results of these model executions here as they were basically at the level of ensuring that no functional group collapsed too often or too quickly, most functional groups persisted and were not too emaciated, and the hydrodynamic model did not sweep excessive nutrients off the shelf.

Forced Catch

The second level forced catch of each fleet based on time series data. Biomass over time was allowed to vary dynamically according to model behavior and biological parameters, largely centered around growth and mortality-related parameters. These biological parameters were tuned at this stage so that the model's estimated biomass for each functional group approximated the stock assessment or survey swept-area estimate time series in magnitude and overall shape.

Dynamic Catch-fixed Effort

The third level started after parameter tuning of the biological parameters was completed. This involved forcing effort of each fleet while allowing catch to vary dynamically. Parameters that affected catch were tuned (primarily catchability of each fleet on each biological group), until the model's estimated catch and biomass approximated the observed time series.

Dynamic Effort

The fourth level started after parameter tuning of the catch parameters was completed, allowing effort to vary dynamically. Parameters that affected effort were tuned (a bottom and top threshold value based on CPUE, which determined if: a fishery increased or decreased its effort; a rate parameter which determined the rate of increase or decrease if it occurred; and a parameter which defined the level of effort per day for the fishery), until the model's estimated effort, catch, and biomass approximated the observed time series.

RESULTS

There is a plethora of results from any one run of an Atlantis model configuration. Here we present a selected set of functional groups that are representative examples of the full range of biota; the rest are presented in Appendices B-E. The representative groups we show here are Atlantic mackerel (*Scomber scombrus*; Atlantis NEUS code FPL); haddock (*Melanogrammus aeglefinus*; Atlantis NEUS code FDO); Atlantic cod (*Gadus morhua*; Atlantis NEUS code FDS); spiny dogfish (*Squalus acanthias*; Atlantis NEUS code SHB); and decapod shrimp (PWN) which included *Pandalus borealis,* other pandalids, paneids, and *Crangon septemspinosa* (Table 2). We also note general patterns of fitting for all taxa or fleets with respect to the levels of tolerance for each run.

Generally speaking, at each level of calibration it was possible to achieve realistic results based on time series data available for biomass, overall catch, catch per fishery, and effort. More specifically, it was possible to recreate the most important time series at approximately the right orders of magnitude and general trajectories.

In what follows, we present the biomass, catch, catch per fleet, and effort results for each functional group or fleet for the fixed catch, fixed effort, and dynamic effort runs. We have presented each graph to show the model output plotted against observed or assessed data in 5 year time blocks. Although Atlantis can output the information in a wide array of formats, we used 5 year time blocks to exhibit major trends and events in the times series while minimizing a higher degree of interannual variability and in an attempt to not draw specific attention to any particular annual event given the more strategic nature of this model's outputs. We also show time series as fitted to data from 1964 - 2004, with an additional 10 years of projections through 2014. We did this to ensure we encapsulated the major dynamics of these groups over time.

Biomasses

Selected Groups

Results for the biomass trajectories from the fixed catch, fixed effort, and dynamic effort runs of the Atlantis NEUS model are all noted here, with some comment on their fit within the range of tolerances. Most functional groups had trajectories that were of a similar order of magnitude for all 3 runs (Figures 6-10). Shrimp was the notable exception, having biomasses generally between 10,000 – 30,000 mt after 1971 in the fixed catch run (Figure 10a) but rising to over 1,000,000 mt in both the fixed effort (Figure 10b) and dynamic effort (Figure 10c) runs. This latter discrepancy for shrimp was corroborated in a subsequent refinement in shrimp stock assessments (see Discussion).

Atlantic mackerel exhibited biomass trajectories that more closely matched the assessment time series in the fixed effort (Figure 6b) and dynamic effort (Figure 6c) runs than was the case with the fixed catch (Figure 6a) run. Particularly, from 1967-1977, the fixed catch run showed a much higher modeled biomass than did the assessment time series, while the fixed effort and dynamic effort runs matched the assessment time series more closely during this range.

For haddock, the biomass trajectories that most closely matched that of the assessment time series were the fixed and dynamic effort runs (Figures 7b,c). The fixed catch (Figure 7a) run showed a relative increase in biomass compared to the assessment time series after 1984. One obvious discrepancy is that the fixed and dynamic effort runs missed a biomass peak that occurred from 1975 to 1984. This discrepancy is due to two strong recruitment year classes (1975 and 1978) that Atlantis NEUS was not parameterized to include.

For Atlantic cod, the fixed catch run (Figure 8a) matched the assessment trajectory reasonably well until about 1990 when the model predicted increasing biomass, while the assessment indicated decreasing and then stable biomass. Both the fixed effort (Figure 8b) and dynamic effort (Figure 8c) runs matched the overall assessment trajectory more closely in later years.

For spiny dogfish, all three model runs performed well through 1984. The fixed catch (Figure 9a) run showed a higher than expected biomass compared to the assessment trajectory, while the other two runs tracked the assessment trajectory more closely. Again, the run which seemed to track the assessment trajectory most closely was the fixed effort run (Figure 9b), while the dynamic effort run (Figure 9c) showed a slightly higher than expected biomass level after 1999.

Other Groups

Generally speaking, Atlantis was able to approximate the assessment biomasses within an order of magnitude and also approximate the assessment biomass trajectories at each level of calibration (Tables 5 and 6; Appendix B). The fixed catch run usually performed worse than the fixed effort run, particularly in approximating the assessment biomass trajectories. This difference was likely due to effort being prescribed by a box when effort was added to the model, as opposed to the more general "catch only" parameters included in the fixed catch run. When effort was modeled dynamically, the match between modeled and assessment biomass trajectories tended to be slightly worse than in the fixed effort runs (as would be expected), but there were some exceptions where the dynamic effort runs matched the assessment trajectories more closely than in the fixed effort run (Appendix B). However, in the dynamic effort run, biomasses for individual groups mostly remained within the acceptable limits of order of magnitude when compared to the assessment biomasses (Tables 5 and 6).

Catches

The fixed catch run results matched the actual catch time series for each functional group (by definition) and are therefore not shown. Most functional groups showed the right order of magnitude and general shape when compared to the observed data (Tables 5 and 7).

For Atlantic mackerel, both the fixed effort (Figure 11a) and dynamic effort (Figure 11b) results matched the general shape of the actual catch time series, but the magnitude of the fixed effort run appeared to be slightly closer to the observed catch than the dynamic effort run.

For haddock, both the fixed effort (Figure 12a) and dynamic effort (Figure 12b) runs approximately matched the general shape of catch of the actual time series, except for the peak corresponding to the strong recruitment class in the biomass figures (Figures 7a-c). The dynamic effort run more closely matched the magnitude of the actual time series compared to the fixed effort run.

For Atlantic cod, both the fixed effort (Figure 13a) and dynamic effort (Figure 13b) runs show the same order of magnitude of catch as the observed data. The fixed effort run more closely matches the overall shape of the actual time series, while the dynamic effort run appears to more closely follow the biomass trajectory of cod as predicted by the model.

For spiny dogfish, both the fixed effort (Figure 14a) and dynamic effort (Figure 14b) runs showed a lower level of catch than did the observed data, but the overall trajectories matched reasonably well. The fixed effort run appeared to perform slightly better when comparing trajectory shapes, and after 2004 (when there was no catch time series available), the two diverged sharply. The fixed effort run predicted stable catches, while the dynamic effort run predicted generally higher catches.

For shrimp, the fixed effort run (Figure 15a) matched the observed catch time series trajectory closely, although observed catch amount was somewhat lower (by about half). The dynamic effort run (Figure 15b) did not match the time series trajectory as closely, but the catches were approximately the same order of magnitude up through 2004, after which the dynamic effort run predicted higher catches for shrimp.

The remainder of the catch results are presented in Appendix C.

Catch per Fleet

We present two catch per fishery figures for each functional group: one for the fixed effort run and one for the dynamic effort run (again, by definition the fixed catch run would be redundant). Each figure has two panels, the top (labeled "Model") is the modeled output and the bottom (labeled "Data") is based on the actual catch time series. The panels show catch broken down by each fishery that targets a functional group.

For Atlantic mackerel the primary fishery was the small pelagic midwater trawl after 1979, with strong fishing pressure by the international small pelagic midwater fleet up until

1978. There were no official catch data available for the international pelagic midwater fleet, which is the reason that the “Data” portion of the graph does not show the estimated catch for this fishery, even though we accounted for it in the model. Both the fixed effort (Figure 16) and dynamic effort (Figure 17) runs predicted these two fisheries as the primary fisheries (and at reasonable magnitudes) on Atlantic mackerel during the appropriate time frame.

For haddock, the primary fishery was the demersal bottom trawl, with the demersal gill net and demersal line fisheries contributing to the overall catch to a much lower degree. In both model runs (Figures 18 and 19), the demersal bottom trawl made up most of the overall catch. The magnitude of the catch by the demersal bottom trawl in the dynamic effort run (Figure 19) was closer to the actual time series than it was in the fixed effort run (Figure 18).

For Atlantic cod, the primary fishery was the demersal bottom trawl, with the demersal gill net and the demersal longline fisheries also showing noticeable catches. The fixed effort run (Figure 20) showed the best overall proportions between these three fisheries in comparison to the observed data. The dynamic effort run (Figure 21) showed a much larger proportion of catch for the demersal longline fishery through the mid 1980s, before it dropped to a proportion closer to the observed data thereafter.

For spiny dogfish, the primary fisheries were the dogfish trawl and the demersal gill net. As mentioned previously, the overall catch was lower in the model than in the observed time series for both the fixed effort and dynamic effort runs. However, in the fixed effort run (Figure 22), the two primary fisheries caught approximately the same proportion of spiny dogfish as the observed data indicated, but other fisheries (small pelagic gill net and small pelagic midwater trawl) caught more in the model run than in the observed data. Both of these fisheries had their catch proportions reduced in the dynamic effort run (Figure 23) to more appropriate levels, with most of the catch by the dogfish trawl and demersal gill net as was seen in the observed data.

For shrimp, the main fishery was the shrimp bottom trawl. The fixed effort run (Figure 24) reasonably matched the catch per fishery time series. The dynamic effort run (Figure 25) was unable to match the catch per fishery time series trajectories but did catch approximately the right order of magnitude starting in the late 1970s until the end of the observed data.

The remainder of the catch per fishery results is presented in Appendix D.

Effort

We present the results for the fisheries that were the primary fleets targeting the representative groups. We also present a few examples of other minor, albeit important, fisheries. Each figure shows the observed time series of effort in days-at-sea for a given fishery from the dynamic effort model run. The forced effort model’s results, by definition, matched the observed data and are not shown here. In general, the effort for each fishery was within an order of magnitude of the observed data (Tables 5 and 8).

The small pelagic midwater trawl fishery (Figure 26) matched the observed data in both overall magnitude and shape up through 2004 (the final year for which we had time series data). Likewise, the international small pelagic midwater trawl fishery (Figure 27) matched the observed data in overall magnitude and shape until 1977, when the enactment of national laws establishing the exclusive economic zone (EEZ) expelled this fishery from operating within the NEUS LME.

The demersal bottom trawl fishery (Figure 28) matched the observed data in both overall magnitude through 2004, although the initial predicted effort up through 1989 is consistently lower. The demersal gill net fishery (Figure 29) also matched the overall shape and magnitude although from 1985-2004 the modeled effort was somewhat lower than the observed time series. As these were the major fleets in the NEUS region, it was imperative that we adequately capture their dynamics.

The benthopelagic demersal trawl fishery (Figure 30) was a modeled fishery which did not capture the major maxima and minima in effort that was seen in the observed data. We observed that minor modifications to the final dynamic effort parameters resulted in exponential increase of effort over the model run. Since the effort was at the right order of magnitude compared to the effort time series for most of the model run (with the largest discrepancy occurring in 1991-1992), we accepted the parameterization as a better alternative than the one which led to exponential effort increases.

The dogfish trawl (Figure 31) and shrimp bottom trawl (Figure 32) fisheries were other examples of fisheries which did not match the specific trajectories of the observed data but generally matched the right order of magnitude. One probable explanation for some of the discrepancies between the observed data and the dynamic effort model outputs is the use of the "Perfect Knowledge" assumption in our effort model. This assumption involves the fleets operating such that they can track all known dynamics of the targeted species, whereas in reality there is always some uncertainty about estimates of the biomass, distribution, and so on for these taxa. The model simulates effort for functional groups which have well known preferred ranges better than it does for more wide-ranging functional groups such as the ones just mentioned. Within the model, this could notably change the distribution of these taxa more easily and often.

The remainder of the effort results are presented in Appendix E.

Spatial Representations

Figures 33-39 show spatially explicit output in an interactive visualization tool (Online Interactive Visualization Environment - OLIVE) for each of the above functional groups from the dynamic effort run. Each box (and depth layer within the box) is indicated on the map, and the time series at the bottom shows abundance over the run of the model in the box indicated by the red dot on the map. The map itself shows the abundance at the specific time indicated in the upper left of the image (the time is also referenced with red triangles at the top and bottom of the time series). Cooler colors (blue, purple) on the map indicate lower abundance, while warmer colors (yellow, orange and red) indicate higher abundance.

It is evident from these figures that these functional groups show reasonable patterns relative to their known (empirically demonstrated) distributions. Atlantic mackerel were predicted to have high biomass along the northern flank of Georges Bank and to a lesser degree in the Gulf of Maine (Figure 33) in the fall, with seasonal migrations evident in the winter (Figure 34). Haddock were predicted to have the highest biomass in the Gulf of Maine and the northern flank of Georges Bank (Figure 35). Atlantic cod (Figure 36) were predicted to have high biomass on the northern flank of Georges Bank. Spiny dogfish (Figure 37) were also predicted to have high biomass on the northern flank of Georges Bank in the fall with seasonal migrations evident in the winter (Figure 38). The shrimp (mainly northern shrimp *Pandalus borealis* and other pandalids) were predicted to primarily occur in the Gulf of Maine, with less biomass of other shrimp species such as panaeids and *Crangon spp.* occurring offshore of southern New England and the Mid Atlantic Bight (Figure 39).

Overall Output and Outcomes

In the final model run that we would propose to use as a baseline for future dynamic modeling scenarios, we were within limits of tolerance (model vs. observed data) at a reasonable level (Tables 5-8). For final biomass outputs we achieved tolerance in 44 out of 45 functional groups. For final catch outputs, we achieved tolerance in 26 out of 35 targeted functional groups, with 27 out of 35 targeted functional groups for catches per fleet. For final effort outputs, we achieved tolerance for 16 out of 18 fleets. These numbers, while not perfect, represent a tradeoff of better fitting in forced scenarios versus allowing the model to dynamically respond and hence adapt to simulated novel strategies. We also note that for those functional groups or fleets whose biomass or catches were outside of our stated range of tolerance, they were generally reasonable representations of observed time series and often represented very minor fisheries that were hard to model or that had minimal/uncertain data inputs. These functional groups or fleets were represented fairly well, again just not within our limits of tolerance. These discrepancies were usually due to differences in timing of events more so than orders of magnitude or general shape of these plots. More germane, the major and most important fleets and biota (ecologically and economically speaking) were well modeled and well within the limits of tolerance.

DISCUSSION

Lessons Learned

Here we summarize those major points that we have gleaned while parameterizing and calibrating the Atlantis NEUS model. We also provide some context and commentary on the model baseline and possible, future improvements and uses.

While Atlantis includes a wide range of options and can be used to create quite complicated models, this capacity must be used carefully. So long as critical drivers and processes are captured, simpler component formulations have substantial predictive power. As an example, despite the immense complexity of the social, political, economic, and regulatory environment of the NEUS LME, the patterns of effort per fleet over the last 40-50 years were quite effectively captured for most fleets by using a model based on simple catch-per-unit effort (CPUE) thresholds, with days-at-sea by a fleet reduced if CPUE dropped below a minimum threshold and days-at-sea increased if CPUE raised above a maximum threshold. The single intervention required for validation and calibration was the imposition of the major regulatory restructuring that occurred in 1994. Thus, while it is widely recognized that all models are simplified approximations of reality (Box 1976, 1979), the art to modeling is to parsimoniously represent a system such that major processes are realistically captured without being over-parameterized or structured. This will likely remain an inherent challenge for an approach such as Atlantis. We trust that the documentation provided demonstrates a reasonable attempt at such parsimony in our modeling approach, given the complexity of an approach such as Atlantis

A major observation from this Atlantis application is that calibration of certain groups (particularly invertebrates such as gelatinous zooplankton, cephalopods, and shrimp) is much more difficult than others. Historical fishery-independent surveys are preferable for informing this process of calibration, and these kinds of data are often much harder to locate for some of the invertebrates. Yet a mismatch between Atlantis predictions and single species models can be insightful rather than simply uninformative or problematic from the perspective of tuning or calibrating. For instance, the shrimp abundance in this Atlantis NEUS model tended to increase under plausible parameterizations in contradiction to the assessments to which we were trying to calibrate. Subsequent revision of the assessment based on new data sources has also found this pattern of increase that was predicted by Atlantis (NEFSC 2007; Link and Idoine 2009). Some species will likely remain underdetermined (e.g., gelatinous zooplankton) and as such, Atlantis models may provide a mechanism for bounding orders of magnitude on estimates of their abundance, as well as a source of information to feedback into the real-world monitoring schemes of such organisms.

While Atlantis can simulate strong or weak year classes, we did not utilize this feature in model calibration to ensure the capturing of the main processes over the time series and not artificially force it to specific events across the broad array of taxa groups modeled. Some of our discrepancies between model runs and the data to which we were calibrating could be attributed to this phenomenon. For instance, Atlantic haddock had an observed spike in biomass (and catch) from 1977-1983 which could be attributed to a strong year class in prior years, but the Atlantis NEUS application was unable to replicate this. In turn this may have affected effort allocations in the dynamic effort run for fisheries which target haddock.

In terms of calibration, and generally speaking, tuning the biology and physics was intuitive and reasonable; the balance among known processes resulted in rational model outputs. This modeling exercise in general and the level of tuning in particular reinforced the fact that one cannot overlook the role of nutrients, physics, primary production, and secondary production in a given LME for the production of LMR. That is, it takes an entire ecosystem to grow a fish. Furthermore, it takes the right kind of ecosystem to grow bigger fish and fisheries of a desirable species mix.

By calibrating with fisheries catch and biology, the tuning was still rather intuitive, but once we moved to calibrating to biology, catch and effort, the tuning was, as expected, more difficult because of the increased number of constraints. Yet this level of constraining, although limiting our parameter space, was useful in that it forced us to focus on our understanding of the system and of which processes had the most influence on all the targeted biota. Thus, from this effort we conclude that calibrated predictions are now possible for LMEs. We note that the precision (variance, exact value, etc.) of those predictions may be less than is typically done, but they are no less accurate (within tolerances of orders of magnitude, directional, etc.) despite the potential lack of precision.

Another thing we learned in the calibration process was that to match the historical record of biological, catch and effort time series, we had to explicitly address tradeoffs. A model application like this explicitly forced us to recognize that we cannot optimize everything simultaneously. As a corollary, this calibration process resulted in the observation that it is very likely that simpler LMR management options are usually better or at least more robust. For instance, tuning to a simple quota was actually more within the levels of tolerance than tuning to dynamic effort controls as modeled.

Modern computing power has eased many computational constraints and facilitates the use of ecosystem models (Beck 1999). Nevertheless model specification, structure, parameterization, and system understanding remain a continued and nontrivial challenge (Silvert 1981; Jørgensen 1994). While there are substantial tradeoffs between the volume of data available for model initialization and time taken to parameterize and calibrate the model (the more data available the longer it takes to initially parameterize the model, but the faster the model can be calibrated), all models benefit from time put into conceptualizing model structure in the first place. Following ecosystem modeling guidelines and best practices, such as those specified in FAO (2008) and NMFS (Townsend et al. 2008), is strongly recommended.

We conclude the lessons learned by noting that patterns are in fact detectable, repeatable, and predictable from complex biophysical systems such as this Atlantis NEUS application.

Value of This Approach

Atlantis' main value is its ability to simulate an entire Management Strategy Evaluation (MSE) cycle, including stock assessments and management actions based on those stock assessments. This use will provide germane advice to fishery managers as to how different management actions will affect the ecosystem modeled, and thus the tradeoffs present with each potential management action. Even without the full MSE module enacted, Atlantis has additional value simply through increasing understanding of a given ecosystem in the parameterization stage. In some cases (c.f. shrimp noted above), Atlantis has predicted biomasses for a functional group widely divergent than was assumed to be the case, only to have later *in situ* observations confirm the simulation results. In other cases, this model has helped to increase our understanding of the precise interactions between functional groups and fisheries.

The use of Atlantis can highlight misunderstanding of ecosystem structure and function as well as unexpected consequences of well-intentioned management options. Even without the fully closed MSE approach enacted, a lot can be learned from Atlantis, especially considering the impacts of different scenarios and forms of management (even if such management is not adaptive, but is in place permanently).

From the inception of Atlantis, cumulative impacts have been an important consideration. The majority of these considerations have revolved around impacts of other industries on water quality, productivity, and the availability of suitable habitat in the coastal zone. Although not largely enacted for Atlantis NEUS, the majority of these are possible with the focus on the nutrient cycle used in Atlantis. This is something that has demarcated the Atlantis approach from other ecosystem models. It is important to address these cumulative impacts because they can also modify the system and so undermine or counteract the effects of fisheries management. Atlantis remains a viable tool to account for such factors.

Limitations of This Approach

Atlantis is a strategic tool and is not appropriate for use in direct support of tactical management decisions. That is, we strongly recommend against setting specific quotas, TACs, etc. (namely, tactical biological reference points, BRPs) by using this modeling approach. None of the parameterizations we have calibrated above would necessarily result in useful or believable tactical LMR management advice. Nor should they. Rather, we emphasize that their purpose is to offer strategic advice from a model such as this Atlantis NEUS application.

Atlantis has many weaknesses – poor ease of use, patchy documentation, large data demands, and long run and calibration times. Many of these are common to all complex models, and one lesson from Atlantis that may be extended to many system models has to do with calibration. The size of these models means that methods such as pattern-oriented modeling (as compared to routine sensitivity analyses) that simultaneously fit multiple parameters against multiple data sets are the only feasible nonheuristic means of calibrating system-level models. Given the observational uncertainty associated with so many data sources (Stow et al. 2009), it is important to focus on accuracy rather than precision. Data should be prioritized so that predictive error against the most trustworthy time series is minimized; so long as output variables are reasonably close (i.e., within the tolerances we noted, e.g. +/- 20%) to estimates from data and the gross patterns in time series and spatial distributions match observed series, then notable periods of calibration time (i.e., months) should not be wasted “chasing the fourth decimal place” of what is ultimately false precision.

This principle also extends to the handling of uncertainty. This consideration is a critical but not straightforward undertaking for system-level models. Classical sensitivity analyses (where parameters are varied systematically, like in Saltelli et al. 2004) are not only impractical, but also confounded by internal model feedbacks, which means that parameter sensitivity is combinatoric and dependent on the time frame being considered (Pantus 2007). While methods that can deal with these issues may already exist in other fields, it is unclear in this case how they need to be identified and adapted. Rather, bounding options in an MSE sense appears to be a reasonable manner, coupled with the calibration noted above, to address this uncertainty.

Next Steps for Atlantis NEUS

The three primary rationales for implementing Atlantis in the NEUS LME were to: (1) increase our understanding of ecosystem dynamics, (2) collaborate with our Australian colleagues (at Commonwealth Scientific and Industrial Research Organization (CSIRO) Marine and Atmospheric Research Division) by using our relatively large data sets to foster the development of this modeling tool in particular and ecosystem modeling in general, and (3) develop a modeling framework that could handle multiple fisheries management scenarios simultaneously so as to explore all the various tradeoffs and indirect effects across a range of management options. Increasingly, the Atlantis NEUS implementation is also being staged for consideration of multiple ocean-use (or multiple sector) issues, with other, nonfishing uses to be included. Currently, the NEUS LME application has gone through all four rounds of model calibration and validation. A number of preliminary scenarios have been run, but we would intend to expand on the suite of scenarios to explore once the Atlantis NEUS application has been fully documented and peer reviewed.

We think that Atlantis NEUS as we have parameterized it can be used to compare management strategies. We also think that novel data and information could allow us to reparameterize the model to more rigorously meet the demands of other disciplines. Examples of potential reparameterizations include: updating the oceanographic submodel inputs with newer outputs data from updated or newer hydrodynamic models, revisiting the spatial resolution of the cells in the model, revising definitions of functional taxa groups, or expanding the use of the socioeconomic modules extant in Atlantis. Yet initially exploring tradeoffs among different management actions, and levels of each action, with the existing Atlantis NEUS application is, although not without its nuances and need for improvements as just noted, likely to be robust as currently parameterized and calibrated.

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Table 1. The assumptions and formulations of ATLANTIS.

Feature	Assumptions and/or formulation notes
General features	
biomass units	mg N/m3
input forcing	nutrients, temperature and physics on interannual, seasonal, tidal frequencies
level of group detail	functional group (with a small number of individual species)
resolution of the formulation used for the invertebrate groups	follow the dynamics of the entire biomass pool of the functional group (or species) in the cell
resolution of the formulation used for the vertebrate groups	follow the biomass dynamics (structural and reserve weight) of the 'average individual' for the functional group (or species) in the cell and the number of individuals in the cell
time step	adaptive* daily or diurnal time step
Process related	
bioturbation and bioirrigation	yes, simple exchange between layers
consumption formulation	type II (asymptotic), with an availability parameter which can be habitat dependent
equations	five general sets of rate of change equations used (autotrophs, invertebrate consumer, vertebrate consumer, bacteria, inanimate)
formulation detail	general: only growth, mortality and excretion explicit
light limitation	optimal irradiance fixed
mixotrophy	yes, for dinoflagellates (if present)
nutrient limitation	external nutrients determine uptake
nutrient ratio	Redfield
oxygen limitation	yes
sediment burial	very low background rate included
sediment chemistry	dynamic, with sediment bacteria
shading of primary producers	yes
spatial (or habitat) limitation	yes (for benthic or demersal groups (and species))
spatial structure	flexible with the potential for multiple vertical and horizontal cells
temperature dependency	yes
transport model used for hydrodynamics flows	yes

* Time steps at this scale (daily or diurnal) may cause instability in variables with fast dynamics (e.g. phytoplankton groups). These groups (all at the base of the food web) use smaller time-steps (adaptive in the sense that to optimize computational efficiency they are as large as they can be without causing instability) which are repeated until full model level time step has been completed. In contrast the higher trophic level groups (and the physical submodels) employ only model level time-steps.

Table 1, continued. The assumptions and formulations of ATLANTIS.

Feature	Assumptions and/or formulation notes
Model closure	
top predators represented by static loss terms	some top predators are included explicitly, but predators not explicitly included in the food web are represented using quadratic mortality terms
mortality terms	linear and quadratic
Vertebrate and fisheries related	
age structure for the vertebrate groups	multiple age classes (or stages, which equate to life phases), with final age class of each group a “plus group”
fishery discards	target and bycatch groups (and species)
incidental mortality due to fishing	yes
invertebrate fisheries	yes
management	variable, may be via effort limitations, gear limitations, minimum legal size, area or temporal closures and may be based on target or endangered stocks
stock-recruit relationship	Beverton-Holt, productivity-based or constant recruitment
stock structure	depends on recruitment function chosen – may be internal (all the stock within the bay and self-seeds) or external (the reproductive stock outside the bay produces the recruits and the oldest age classes migrate out of the bay to join this stock)

Table 2. The functional groups are shown with their ATLANTIS NEUS code, the group name, and the species included each group. In some instances (e.g., Atlantic mackerel, only one species was included in the group and thus the group and species names are identical). Additionally, the initial biomass for each group is shown.

CODE	GROUP	SPECIES	INITIAL BIOMASS
FPL	Atlantic mackerel	Atlantic mackerel	6637.5
FPS	Atlantic herring	Atlantic herring	4886.5
FVD	White hake	White hake	32303.9
FVS	Bluefish	Bluefish	2697
FVB	Other piscivores	Flounder (fourspot, windowpane, gulfstream, summer, winter, witch), Atlantic halibut, hogchoker, American plaice	94801.7
FVT	Large piscivores	Marlin (blue, white), swordfish, tuna (albacore, big eye, blackfin, bluefin, little)	4837.6
FMM	Migratory mesopelagics	Myctophids (lanterfish, pearlsides)	20.8
FBP	Benthopelagics	Argentine, bay anchovy, striped anchovy, butterfish, sandlance, harvest fish, Atlantic silverside, round herring, chub mackerel, halfbeak	23718.1
FDD	Goosefish	Goosefish	38974.7
FDE	Shallow demersal fish	Alewife, gizzard shad, blueback herring, mehaden, hickory shad, American shad, smelt	6329.9
FDS	Atlantic cod	Atlantic cod	93206
FDB	Silver hake	Silver hake	36660.8
FDC	Miscellaneous demersals	57 spp (Note 1)	261600.6
FDO	Haddock	Haddock	126222.4
FDF	Yellowtail flounder	Yellowtail flounder	30212.8
SHB	Spiny dogfish	Spiny dogfish	306781.5
SHD	Other demersal sharks	Dogfish (chain, smooth), sharks (Atlantic angel, sandbar, porbeagle, nurse, sand tiger, bull, lemon, sharpnose, scalloped hammerhead, thresher)	18788.6
SHP	Pelagic sharks	Sharks (blue, dusky, great hammerhead, shortfin mako, white, blacknose, silky, blacktip, tiger, finetooth, bignose)	7183.5
SSK	Skates and rays	Skates (barndoor, clearnose, little, rosette, smooth, winter, thorny), Atlantic torpedo, bullnose ray, cownose ray, spotted eagle ray, stingrays (bluntnose, roughtail, Atlantic, yellow)	138910.7
SB	Seabirds	Shearwaters (Cory's, greater, sooty), gulls (great black-backed, herring, laughing), northern garnet, black-legged kittiwake, northern fulmar, Wilson's storm petrel, red phalarope	1808.5
PIN	Pinnipeds	Seals (grey, harbor, harp, hooded)	7660.8
REP	Reptiles	Turtles (green, leatherback, loggerhead, ridley)	803.2

Note 1: Offshore hake, pollock, red hake, spotted hake, rockling (fourbeard, threebeard), cusk, roundnose grenadier, snipefish, John Dory, stickleback, pipefish, trumpetfish, Atlantic moonfish, lookdown, Atlantic croaker, black sea bass, scup, weakfish, northern kingfish, black drum, silver perch, spot, tilefish, scorpionfish, redfish, blackbelly rosefish, sculpins (longhorn, moustache, shorthorn), sea raven, sea robin (armored, northern, striped, other), striped bass, tautog, cunner, eel (American, conger and uncl.), northern puffer, ocean pout, wolfish, wrymouth, garfish, hagfish, hogfish, lumpfish, oyster toadfish, sand perch, Atlantic needlefish, Atlantic salmon, sheepshead, spot, sturgeons, tomcod, lizardfishes

Table 2, continued. The functional groups are shown with their ATLANTIS NEUS code, the group name, and the species included each group. In some instances (e.g., Atlantic mackerel, only one species was included in the group and thus the group and species names are identical). Additionally, the initial biomass for each group is shown.

CODE	GROUP	SPECIES	INITIAL BIOMASS
WHB	Baleen whales	Fin, humpback, minke, right, sei	90230.7
WHT	Toothed whales	Beaked whale, dolphin (bottlenose, common, risso, spotted, striped, whiteside), harbor porpoise, pilot whales, sperm whale	19997.4
CEP	Squid	Illex, Loligo	74365.7
BFS	Sea scallop	Sea scallop	56370
BFF	Other benthic filter feeder	14 groups (Note 2)	1812530.5
BG	Benthic grazer	Echinoids, selected amphipods, gastropods	5035438.6
BML	Lobster	Lobster	20570.6
BMS	Shallow macrozoobenthos	14 spp (Note 3)	803480.2
PWN	Shrimp	Northern shrimp, (*Pandalus borealis* & other pandalids), sand shrimp, pink shrimp, brown shrimp (& other paneids)	19488.8
ZL	Carnivorous zooplankton	Euphausiids, mysids, chaetognaths, tunicates, hyperiids	527309.6
BD	Deposit feeder	15 taxa groups (Note 4)	375230138.3
BC	Benthic carnivore	Selected gastropods, selected annelids, octopods, starfish	6025037.3
ZG	Gelatinous zooplankton	Ctenophores, siphonophores, salps, coelenterates, scyphozoans	903571.9
PL	Diatoms		2494086.8
DF	Dinoflagellates		914795.7
PS	Pico-phytoplankton		742789.1
ZM	Copepods	Copepods (various calanoid spp.)	562723.7
ZS	Microzooplankton		2228999.9
PB	Pelagic bacteria		31842.8
BB	Sediment bacteria		15062593.3
BO	Meiobenthos		60250373.3

Note 2: Bay scallop, ocean quahog, surf clam, porifera, hydrozoa, anthozoa, selected annelids, other bivalves, cirripedia, bryozoa, brachiopoda, crinoidea, hemichordate, ascidians

Note 3: Crabs (blue, cancer, green, hermit, horseshoe, jonah, lady, queen snow, red, rock, spider), knobbed whelk, asteroids

Note 4: Platyhelminthes, Nemertea, Annelida, Pogonophora, Sipuncula, Echiura, Polyplacophora, Pycnogoda, Cumacea, Isopoda, Amphipoda (selected groups), Stomatopoda, Decapoda (selected groups), Holothuroidea, Ophiuroidea

Table 3. This table shows the ATLANTIS NEUS fishery codes along with the description and swept area of gear.

Fishery Code	Description	Swept Area (m^3)
dlineFD	Line fishery on demersals	33609600
dredgeBFS	Scallop dredge	17334080
dtrawlCEP	Demersal trawl on cephalopods	41670000
dtrawlFBP	Demersal trawl on benthopelagics	435297600
dtrawlFD	Demersal trawl on other deep demersals	90004000
dtrawlFDB	Demersal trawl on shallow demersals	5000400
dtrawlFDO	Demersal trawl on cod and haddock	1680480
midwcCEP	Midwater trawl on cephalopods	4167000
midwcFD	Midwater Trawl - international fleet	77500600
midwcFP	Midwater trawl on small pelagics	90500600
netFD	Demersal gillnet on other deep demersals	259200000
plineFVO	Pelagic line on tuna and sharks	2666880
pseineFP	Purse seine on small pelagics	7853981.6
pseineFVO	Purse seine on tuna and sharks	370.4
ptrawlPWN	Shrimp trawl	8334000
REC	Recreational fishery	12090
trapBMS	Lobster traps	2880000
trapFDE	Trap on demersals	5334000

Table 4. The targeted groups for each fishery are indicated with a 'T' and the fisheries which include bycatch of a group are indicated with a 'B' in the appropriate cell.

		GEAR											
CODE	**GROUP**	midwcCEP	midwcFP	dredgeBFS	netFD	plineFVO	pseineFVO	pseineFP	trapBMS	trapFD	dtrawlCEP	dtrawlFD	dtrawlFDB
BC	Benthic carnivore											B	B
BD	Deposit feeder											B	B
BFS	Sea scallop			T									B
BFF	Other benthic filter feeder			B									B
BG	Benthic grazer												
BMS	Shallow macrozoobenthos								T			B	B
BML	Lobster								T				
CEP	Squid	T									T		B
PWN	Shrimp												
FDD	Goosefish				T					T		T	
FDS	Atlantic cod												T
FMM	Migratory mesopelagics											B	
FBP	Benthopelagics												
FPL	Atlantic mackerel		T					T					B
FPS	Atlantic herring		T					T					
FDB	Silver hake												T
FDC	Miscellaneous demersals				T					T		T	
FDO	Haddock												
FVD	White hake											T	
FDE	Shallow demersal fish												T
FDF	Yellowtail flounder				T							T	
FVS	Bluefish												B
FVB	Other piscivores												B
FVT	Large piscivores					T	T						
PIN	Pinnipeds		B		B								B
SB	Seabirds					B							
SHB	Spiny dogfish											B	B
SHD	Other demersal sharks											B	B
SHP	Pelagic sharks					T							
SSK	Skates and rays											B	B
WHB	Baleen whales				B								
WHT	Toothed whales							B					
REP	Reptiles												B
ZG	Gelatinous zooplankton											B	B
ZL	Carnivorous zooplankton												

Table 4, continued. The targeted groups for each fishery are indicated with a 'T' and the fisheries which include bycatch of a group are indicated with a 'B' in the appropriate cell.

		GEAR						
CODE	**GROUP**	dtrawlFDO	midwcFD	dlineFD	REC	ptrawlPWN	dtrawlFBP	trapFDE
BC	Benthic carnivore	B					B	
BD	Deposit feeder	B					B	
BFS	Sea scallop				T		B	
BFF	Other benthic filter feeder				T		B	
BG	Benthic grazer				T			
BMS	Shallow macrozoobenthos				T		B	B
BML	Lobster				T			
CEP	Squid				T			
PWN	Shrimp				T	T		
FDD	Goosefish		T	T				
FDS	Atlantic cod				T			
FMM	Migratory mesopelagics		B					
FBP	Benthopelagics				T		T	
FPL	Atlantic mackerel				T			
FPS	Atlantic herring				T			
FDB	Silver hake				T			T
FDC	Miscellaneous demersals			T			B	
FDO	Haddock	T						
FVD	White hake		T	T				
FDE	Shallow demersal fish				T			T
FDF	Yellowtail flounder			T				
FVS	Bluefish				T			
FVB	Other piscivores				T			T
FVT	Large piscivores				T			
PIN	Pinnipeds							
SB	Seabirds			B				
SHB	Spiny dogfish						B	
SHD	Other demersal sharks				T			
SHP	Pelagic sharks				T			
SSK	Skates and rays				T		B	
WHB	Baleen whales							
WHT	Toothed whales							
REP	Reptiles			B	T			
ZG	Gelatinous zooplankton							
ZL	Carnivorous zooplankton							

Table 5. Levels of tolerance for each step of ATLANTIS calibration

Biophysical	Tuning physics and background for biota Hydrodynamic model doesn't sweep nutrients off shelf Nothing dies too often or too quickly Most spp persist and aren't too emaciated
Fixed Catch, no Effort	Tuning biological groups and processes to observed levels of catch Can have exploitation so that none of the biology dies outright Most (~>75%) biomass trajectories within +/- 1 orders of magnitude (OOM)
Dynamic Catch, Fixed Effort	Tuning catch to effort Most (~85%) biomass trajectories and shapes within +/- 0.5 OOM Most (~75%) catch trajectories within +/- 1 OOM
Dynamic Effort	Letting fleet behavior be tuned to effort Most biomass (~90%) and catch (~80%) trajectories & shapes within +/- 0.5 & 1 OOM, respectively Most (~85%) effort trajectories and shapes within +/- 1 OOM

Table 6. Levels of tolerance for each functional group for each ATLANTIS NEUS model run, with regards to biomass trajectories. Y = yes, if the group matched the tolerance criteria (Table 5) for a given model run; N = no if it didn't match the tolerance criteria; Marginal = either the magnitude was generally acceptable, or the shape or timing of the data trajectories were acceptable, but not both. No TS = there was no corresponding observed data time series available to compare the model runs against, but magnitudes were checked against point estimates or expert opinion, as indicated by the notes.

			MODEL RUN	
CODE	**GROUP**	**Fixed Catch**	**Fixed Effort**	**Dynamic Effort**
FPL	Atlantic mackerel	Y	Y	Y
FPS	Atlantic herring	Marginal	Y	Y
FVD	White hake	Y	Y	Y
FVS	Bluefish	Y	Y	Y
FVB	Other piscivores	Y	Y	Y
FVT	Large piscivores	No TS[1]	No TS[1]	No TS[1]
FMM	Migratory mesopelagics	Y	Y	Y
FBP	Benthopelagics	Y	Y	Y
FDD	Goosefish	Marginal	Y	Marginal
FDE	Shallow demersal fish	Y	Marginal	Marginal
FDS	Atlantic cod	Y	Y	Y
FDB	Silver hake	Y	Y	Y
FDC	Miscellaneous demersals	Y	Y	Y
FDO	Haddock	Y	Y	Y
FDF	Yellowtail flounder	Y	Y	Y
SHB	Spiny dogfish	Y	Y	Y
SHD	Other demersal sharks	Y[a]	Y[a]	Y[a]
		No TS[1]	No TS[1]	No TS[1]
SHP	Pelagic sharks	OK	OK	OK
SSK	Skates and rays	Y[a]	Y[a]	Y[a]
		No TS[1]	No TS[1]	No TS[1]
SB	Seabirds	OK	OK	OK
		No TS[1,2]	No TS[1,2]	No TS[1,2]
PIN	Pinnipeds	N	OK	OK
		No TS[1,3]	No TS[1,2]	No TS[1,2]
REP	Reptiles	Marginal	OK	OK
		No TS[1,4]	No TS[1,4]	No TS[1,4]
WHB	Baleen whales	OK	OK	Marginal
		No TS[1,4]	No TS[1,4]	No TS[1,4]
WHT	Toothed whales	OK	OK	OK
CEP	Squid	Y[a]	Y	Y
BFS	Sea scallop	Y	Y	Y
BFF	Other benthic filter feeder	Y	Y	Y
BG	Benthic grazer	No TS[1]	No TS[1]	No TS[1]

Note a – compared to survey estimates, not assessments

Note 1 – Magnitude compared to point estimates from Link et al. (2006) and sources therein.

Note 2 – G. Waring, pers. comm.

Note 3 – H. Haas, pers. comm.

Note 4 – D. Palka, pers. comm.

Table 6, continued. Levels of tolerance for each functional group for each ATLANTIS NEUS model run, with regards to biomass trajectories. Y = yes, if the group matched the tolerance criteria (Table 5) for a given model run; N = no if it didn't match the tolerance criteria; Marginal = either the magnitude was generally acceptable, or the shape or timing of the data trajectories were acceptable, but not both. No TS = there was no corresponding observed data time series available to compare the model runs against, but magnitudes were checked against point estimates or expert opinion, as indicated by the notes.

CODE	GROUP	MODEL RUN Fixed Catch	Fixed Effort	Dynamic Effort
BML	Lobster	Y	Y	Y
BMS	Shallow macrozoobenthos	No TS[1]	No TS[1]	No TS[1]
PWN	Shrimp	Marginal	Marginal	Marginal
ZL	Carnivorous zooplankton	No TS[1]	No TS[1]	No TS[1]
BD	Deposit feeder	No TS[1]	No TS[1]	No TS[1]
BC	Benthic carnivore	No TS[1]	No TS[1]	No TS[1]
ZG	Gelatinous zooplankton	No TS[1]	No TS[1]	No TS[1]
PL	Diatoms	No TS[1]	No TS[1]	No TS[1]
PS	Pico-phytoplankton	No TS[1]	No TS[1]	No TS[1]
ZM	Copepods	No TS[1]	No TS[1]	No TS[1]
ZS	Microzooplankton	No TS[1]	No TS[1]	No TS[1]
PB	Pelagic bacteria	No TS[1]	No TS[1]	No TS[1]
BB	Sediment bacteria	No TS[1]	No TS[1]	No TS[1]
BO	Meiobenthos	No TS[1]	No TS[1]	No TS[1]
	Within Tolerances	23	26	24
	Marginal	4	2	4
	Outside Tolerances	1	0	0
	Percentage which matched tolerances	96.40%	100%	100%
	(discounting marginals)	(89.3%)	(96.4%)	(92.8%)

Note a – compared to survey estimates, not assessments

Note 1 – Magnitude compared to point estimates from Link et al. (2006) and sources therein.

Note 2 – G. Waring, pers. comm.

Note 3 – H. Haas, pers. comm.

Note 4 – D. Palka, pers. comm.

Table 7. Levels of tolerance for each functional group for each ATLANTIS NEUS model run, with regards to catch trajectories. Y = yes, if the group matched the tolerance criteria (Table 5) for a given model run; N = no if it didn't match the tolerance criteria; Marginal = either the magnitude was generally acceptable, or the shape or timing of the data trajectories were acceptable, but not both. No TS = there was no corresponding observed data time series available to compare the model runs against; N/A means that it was not appropriate for the group to be considered as catch, even if it was incidental bycatch. N/A and No TS values were not considered in the calculations.

		MODEL RUN	
CODE	GROUP	Fixed Effort	Dynamic Effort
FPL	Atlantic mackerel	Y	Y
FPS	Atlantic herring	Marginal	Y
FVD	White hake	Y	Y
FVS	Bluefish	Y	Y
FVB	Other piscivores	Marginal	Marginal
FVT	Large piscivores	Y	Marginal
FMM	Migratory mesopelagics	N/A	N/A
FBP	Benthopelagics	Y	Y
FDD	Goosefish	N	Y
FDE	Shallow demersal fish	Y	N
FDS	Atlantic cod	Y	Y
FDB	Silver hake	Y	Y
FDC	Miscellaneous demersals	Y	Y
FDO	Haddock	Y	Y
FDF	Yellowtail flounder	Y	Y
SHB	Spiny dogfish	Y	Y
SHD	Other demersal sharks	Y	Marginal
SHP	Pelagic sharks	No TS[1]	No TS[1]
SSK	Skates and rays	Marginal	Marginal
SB	Seabirds	No TS[1]	No TS[1]
PIN	Pinnipeds	No TS[1]	No TS[1]
REP	Reptiles	No TS[1]	No TS[1]
WHB	Baleen whales	No TS[1]	No TS[1]
WHT	Toothed whales	No TS[1]	No TS[1]
CEP	Squid	Y	Y
BFS	Sea scallop	Y	N
BFF	Other benthic filter feeder	N	N
BG	Benthic grazer	N/A	N/A
BML	Lobster	Y	N
BMS	Shallow macrozoobenthos	Y	N

[1] Bycatch, no directed catches on these groups. Statistics only for targeted groups.

Table 7, continued. Levels of tolerance for each functional group for each ATLANTIS NEUS model run,

		MODEL RUN	
CODE	GROUP	Fixed Effort	Dynamic Effort
PWN	Shrimp	Marginal	Marginal
ZL	Carnivorous zooplankton	N/A	N/A
BD	Deposit feeder	N/A	N/A
BC	Benthic carnivore	N/A	N/A
ZG	Gelatinous zooplankton	N/A	N/A
PL	Diatoms	N/A	N/A
PS	Pico-phytoplankton	N/A	N/A
ZM	Copepods	N/A	N/A
ZS	Microzooplankton	N/A	N/A
PB	Pelagic bacteria	N/A	N/A
BB	Sediment bacteria	N/A	N/A
BO	Meiobenthos	N/A	N/A
	Within Tolerances	17	13
	Marginal	4	5
	Outside Tolerances	2	5
	Percentage which matched tolerances (discounting marginals)	91.30% (82.6%)	78.20% (67.4%)

[1] Bycatch, no directed catches on these groups. Statistics only for targeted groups.

Table 8. Levels of tolerance for each fishery for each ATLANTIS NEUS model run, with regards to effort trajectories. Y = yes, if the group matched the tolerance criteria (Table 5) for a given model run; N = no if it didn't match the tolerance criteria; Marginal = either the magnitude was generally acceptable, or the shape or timing of the data trajectories were acceptable, but not both.

FISHERY	MODEL RUN Dynamic Effort[1]
midwcCEP	Marginal
midwcFP	Y
dredgeBFS	Y
netFD	Y
plineFVO	Y
pseineFVO	Y
pseineFP	Y
trapBMS	Marginal
dtrawlCEP	Y
dtrawlFD	Y
dtrawlFDB	N
dtrawlFDO	Marginal
midwcFD	Y
dlineFD	Y
ptrawlPWN	Y
dtrawlFBP	Marginal
trapFDE	Y
Within Tolerances	12
Marginal	4
Outside Tolerances	1
Percentage which matched tolerances (discounting marginals)	94.10% (82.3%)

Note 1- recreational fisheries were not included in this calculation due to data input uncertainties, but were a part of the model.

FIGURES

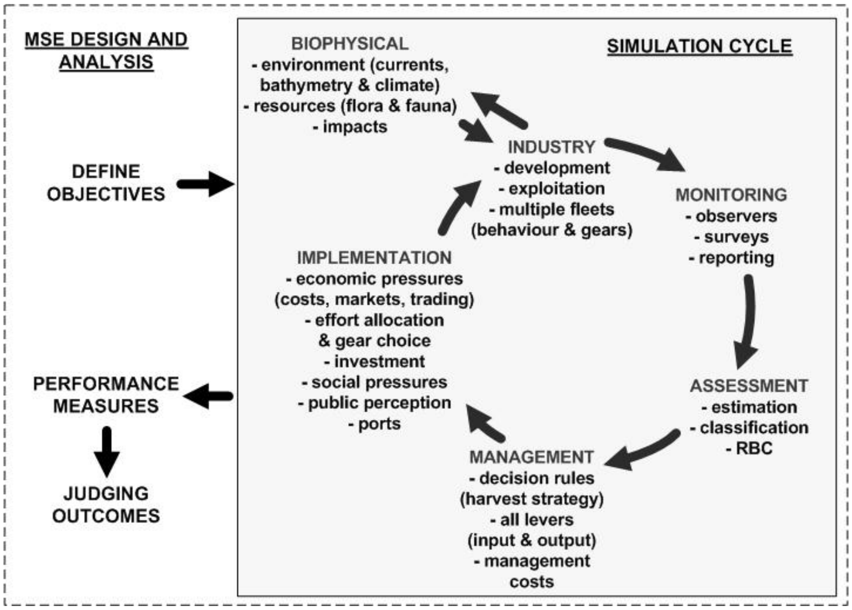


Figure 1. The specific steps of the management strategy and adaptive management cycles are explicitly modelled within Atlantis. Adapted from Fulton et al. (2004a, 2004c, 2004d). MSE = management strategy evaluation, RBC = recommended biological catch.

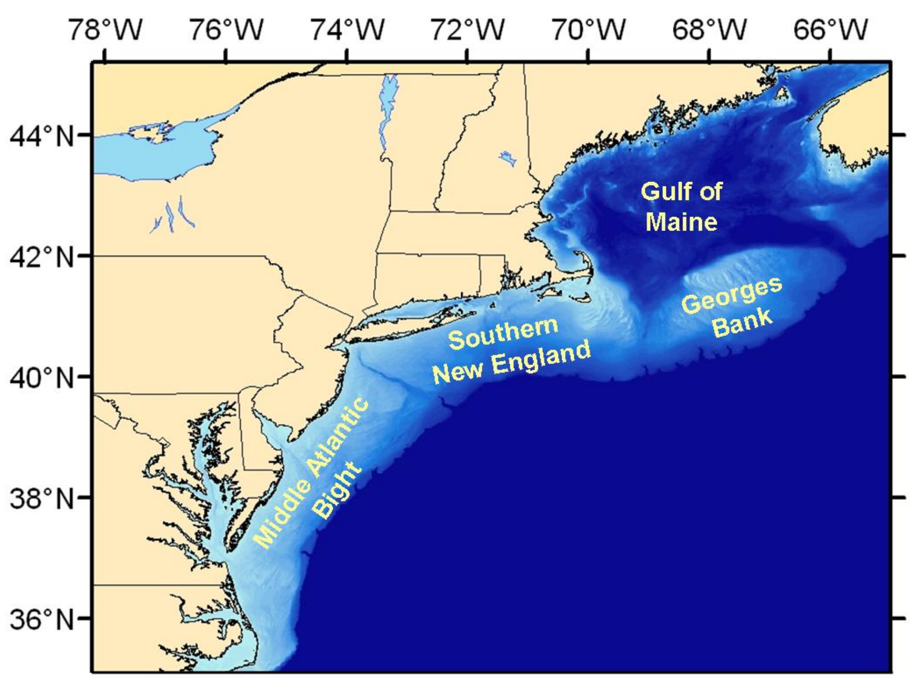


Figure 2. The NEUS LME is composed of four separate subregions: Gulf of Maine, Georges Bank, Southern New England, and Mid Atlantic Bight.

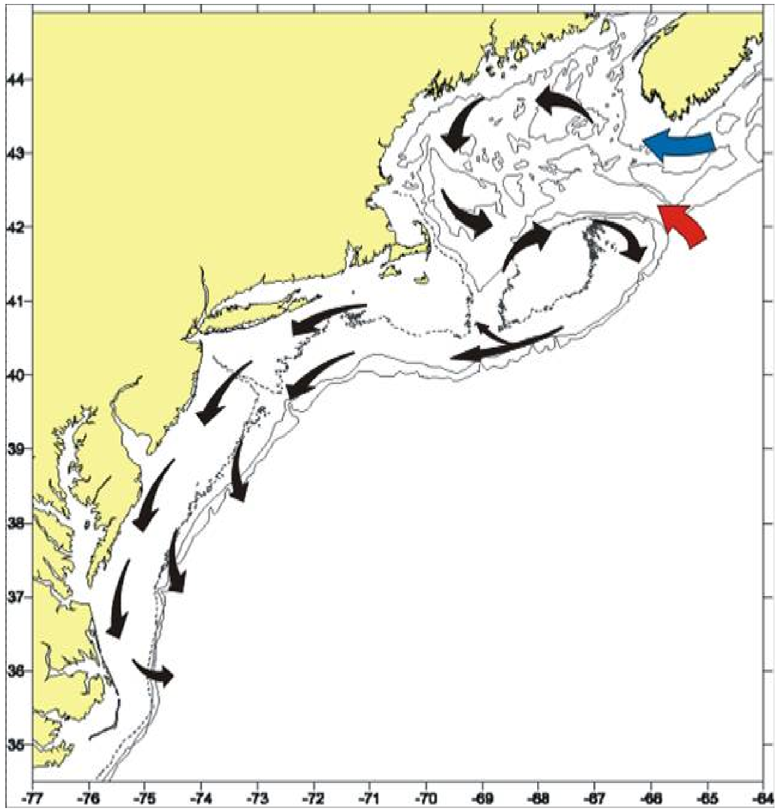


Figure 3. The arrows show the general pattern of circulation in the NEUS LME. Water enters the system from the colder (blue) Labrador Shelf (A) and deep ocean slope wamer (red) water through the Northeast Channel (B), and leaves the northern part of the system primarily through the Great South Channel (C) and offshore flow fields near Cape Hatteras (D).

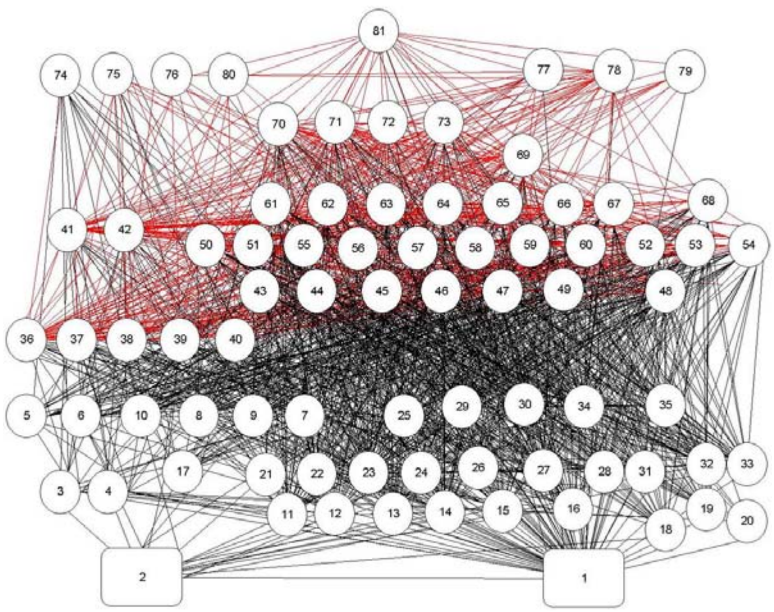
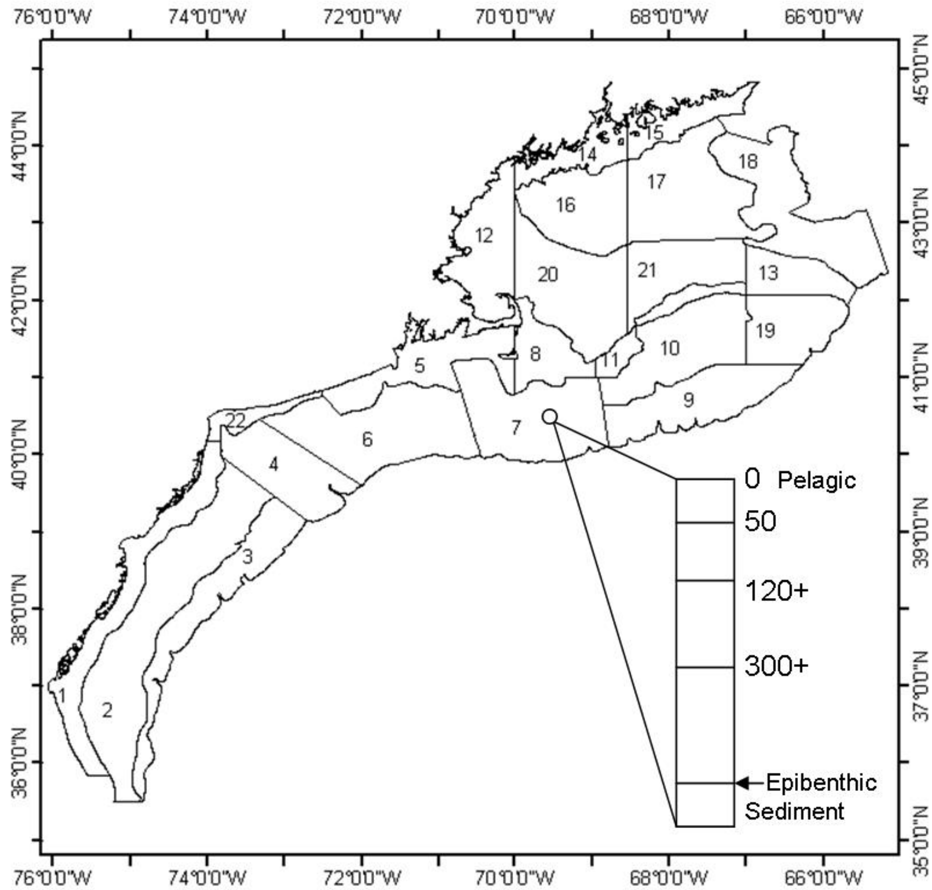
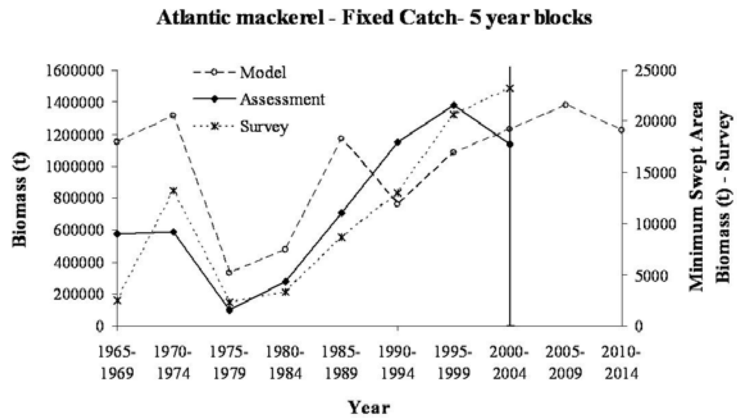


Figure 4. The NEUS LME food web adapted from Link (2002). Red flows indicate predation on fish and upper trophic levels, black on invertebrates and lower trophic levels. The numbers represent various species or species groups in the ecosystem (see Link 2002 for further details).



Region	Model boxes
Mid Atlantic Bight:	1-4, W part of 6, 22
Hudson Canyon area:	4, SW part of 22
Southern New England (SNE):	5, E part of 6, W part of 7
Georges Bank (GB):	E part of 7, 8-11, 19
Great South Channel of GB:	8
Southern flank of GB:	9
Northern flank of GB:	11
Gulf of Maine (GoM):	12, 14-17, 20-21
Coastal GoM:	12, 14, 15
Wilkinson Basin:	16, 20
Jordan Basin:	17, 21
Georges Basin	E part of 11
Western Scotian shelf:	13, 18
Northeast Channel:	13
Massachusetts Bay:	S part of 12
Bay of Fundy:	E part of 15

Figure 5. The NEUS LME as modeled spatially by Atlantis. There are 22 dynamically modeled horizontal regions (or boxes). Each region is further modeled as having multiple depth layers: up to four water column layers in the case of Atlantis NEUS, with an epibenthic layer and a sediment layer. There are also 8 boundary boxes which primarily control migration of groups into and out of the system, and are not shown here. Locations of several prominent geographic features are noted.



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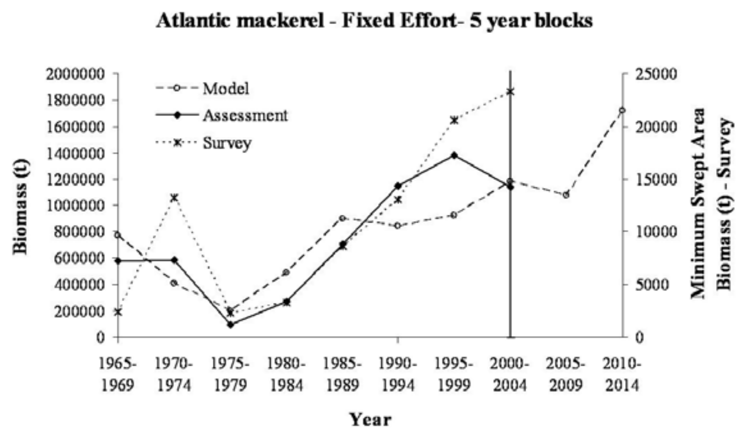

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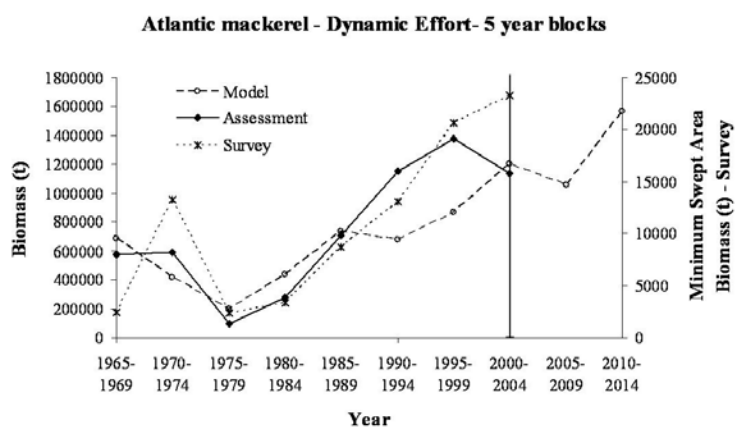
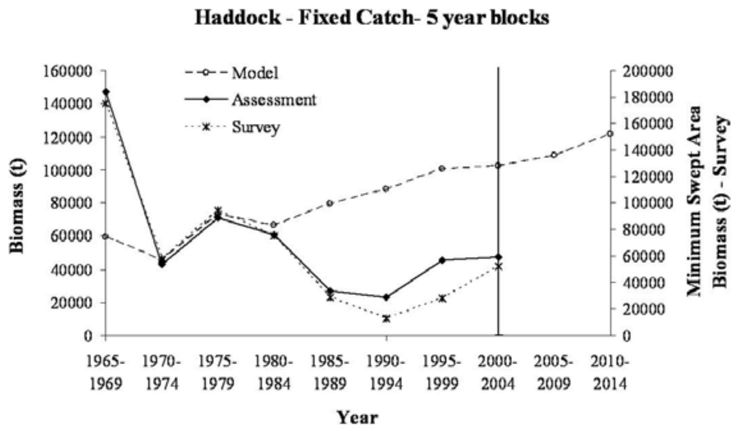


c.

Figure 6. Atlantic mackerel (*Scomber scombrus*) biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



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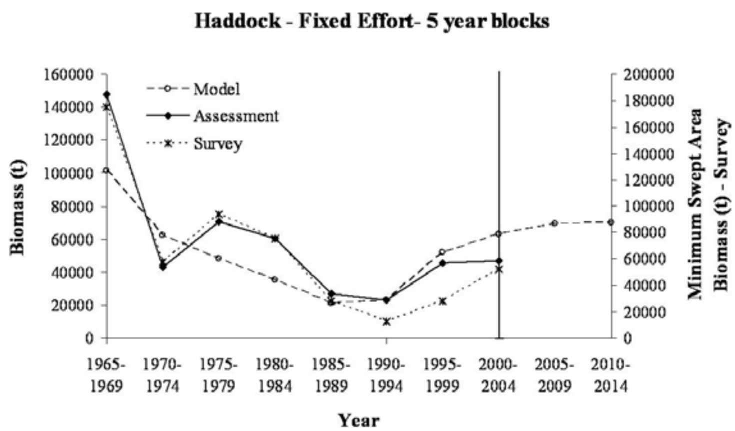

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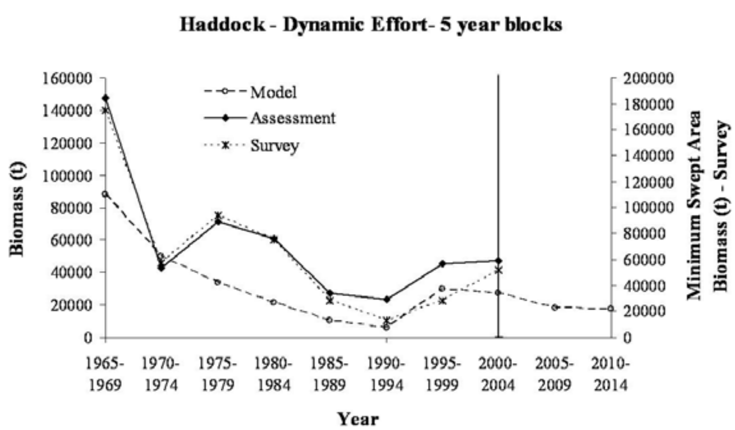
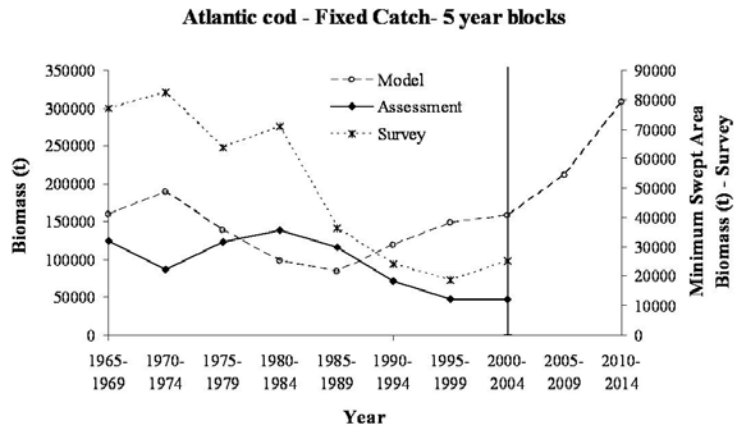


c.

Figure 7. Haddock (*Melanogrammus aeglefinus*) biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



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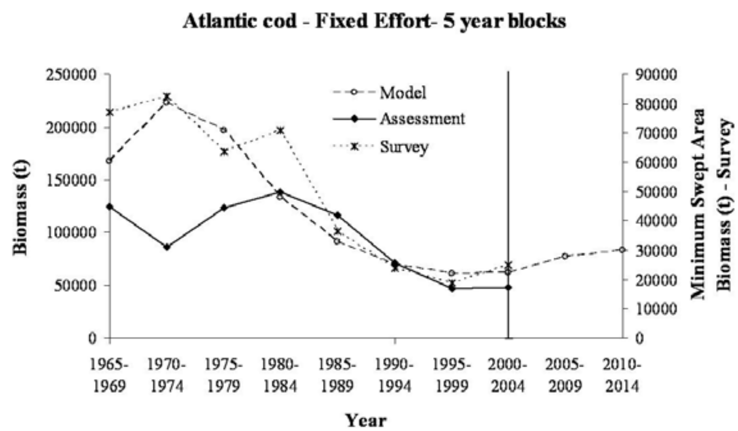

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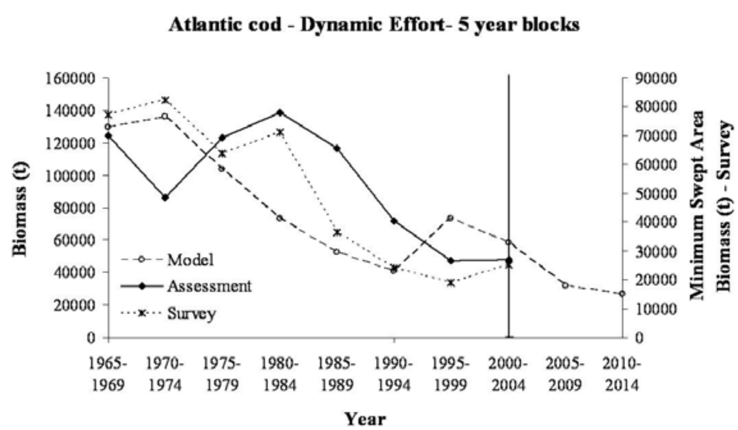
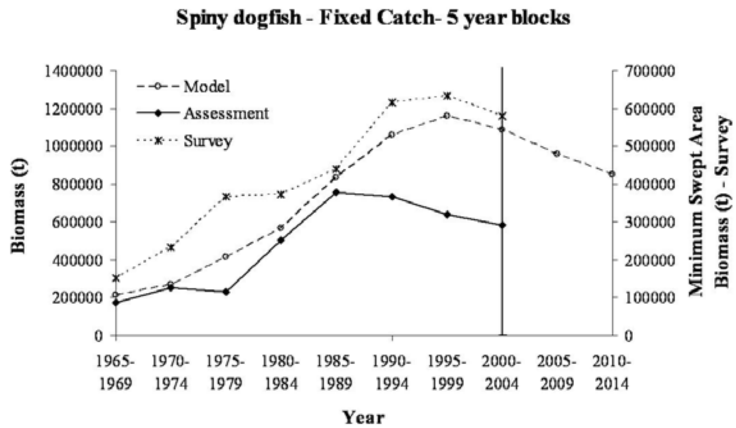


c.

Figure 8. Atlantic cod (*Gadus morhua*) biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



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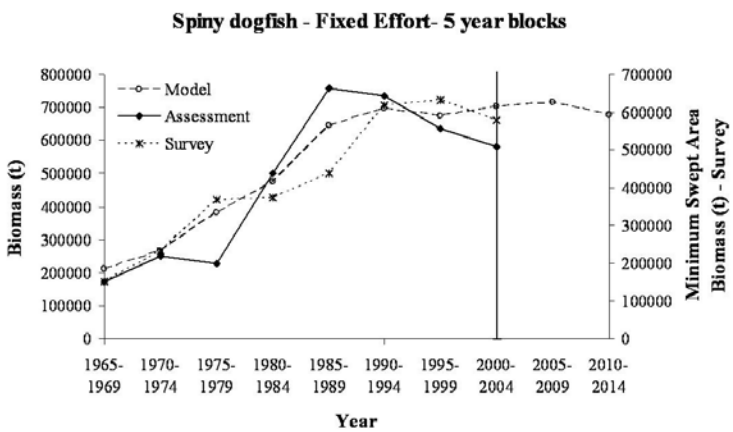

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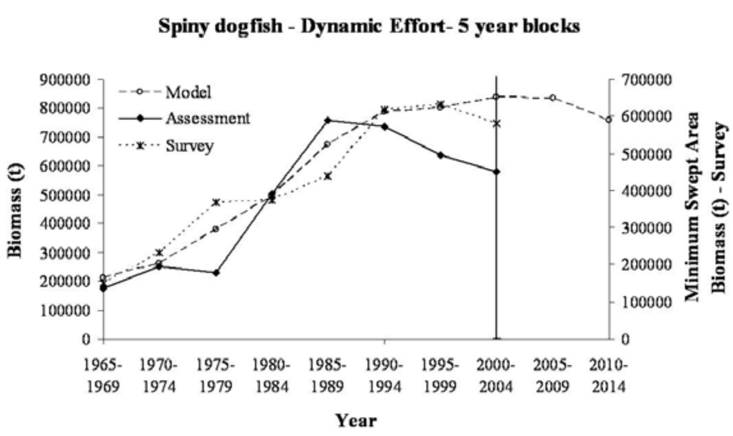
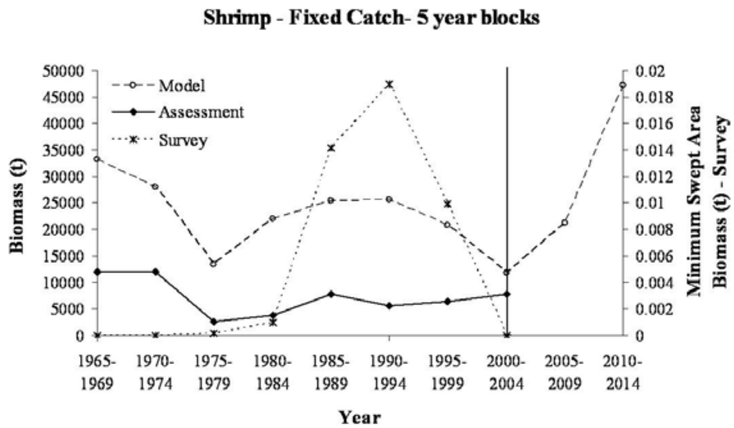


c.

Figure 9. Spiny dogfish (*Squalus acanthias*) biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



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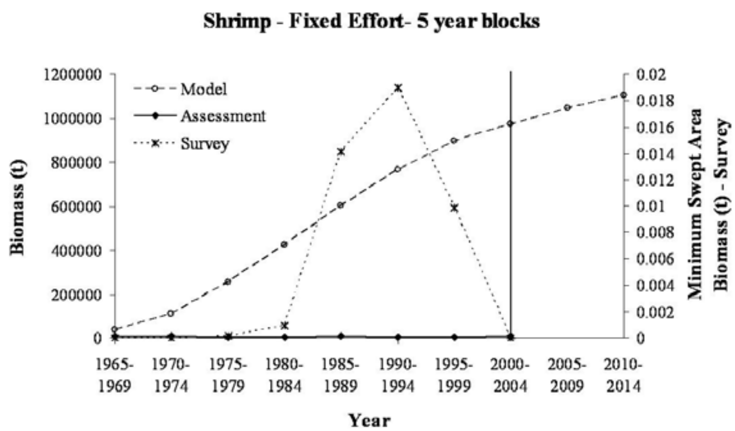

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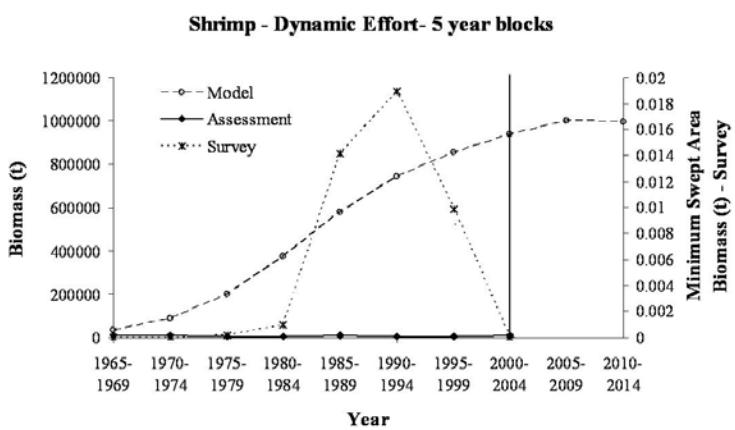
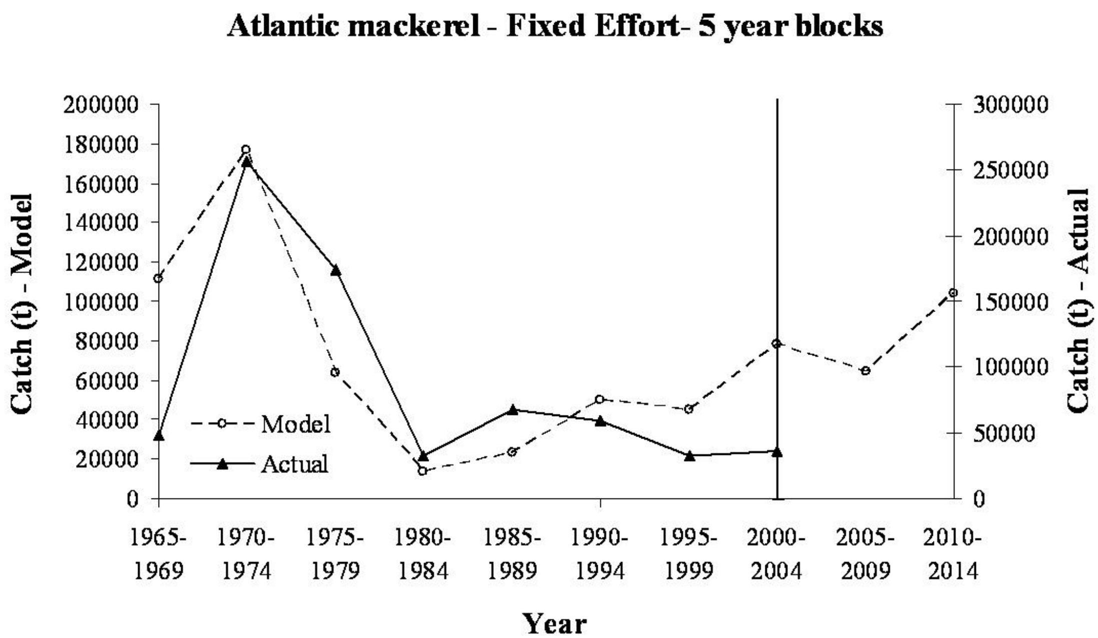


c.

Figure 10. Shrimp biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



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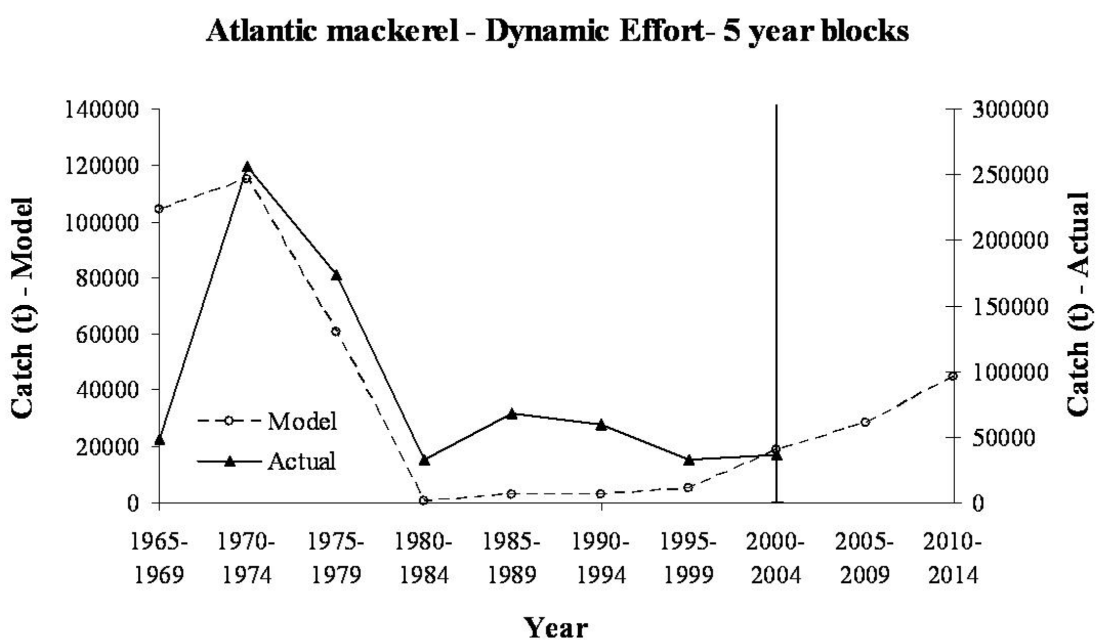

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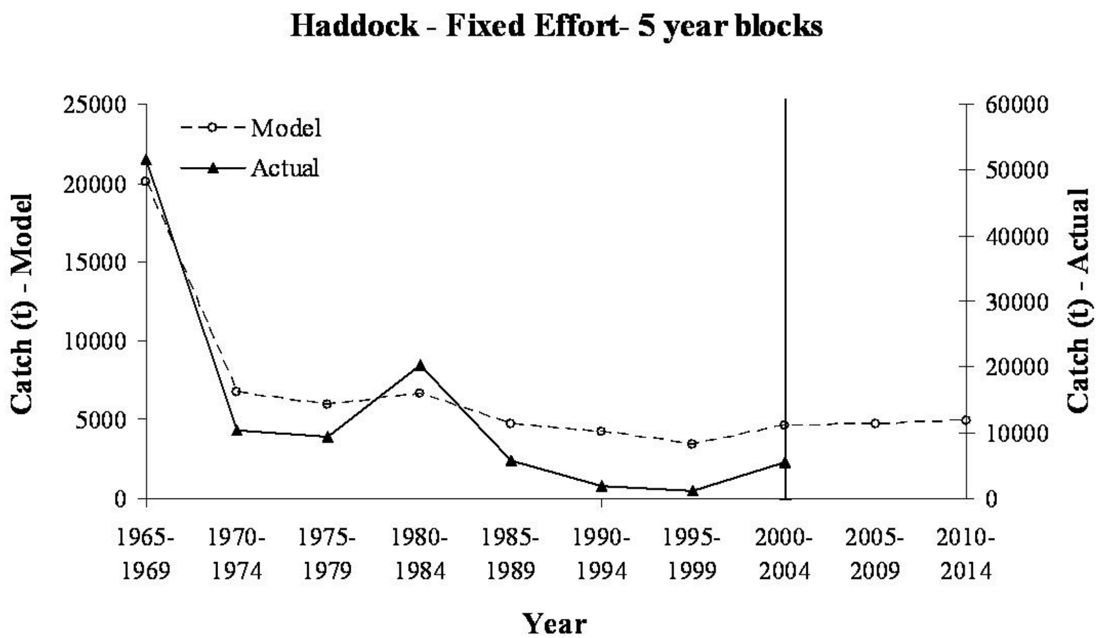
Figure 11. Atlantic mackerel (*Scomber scombrus*) catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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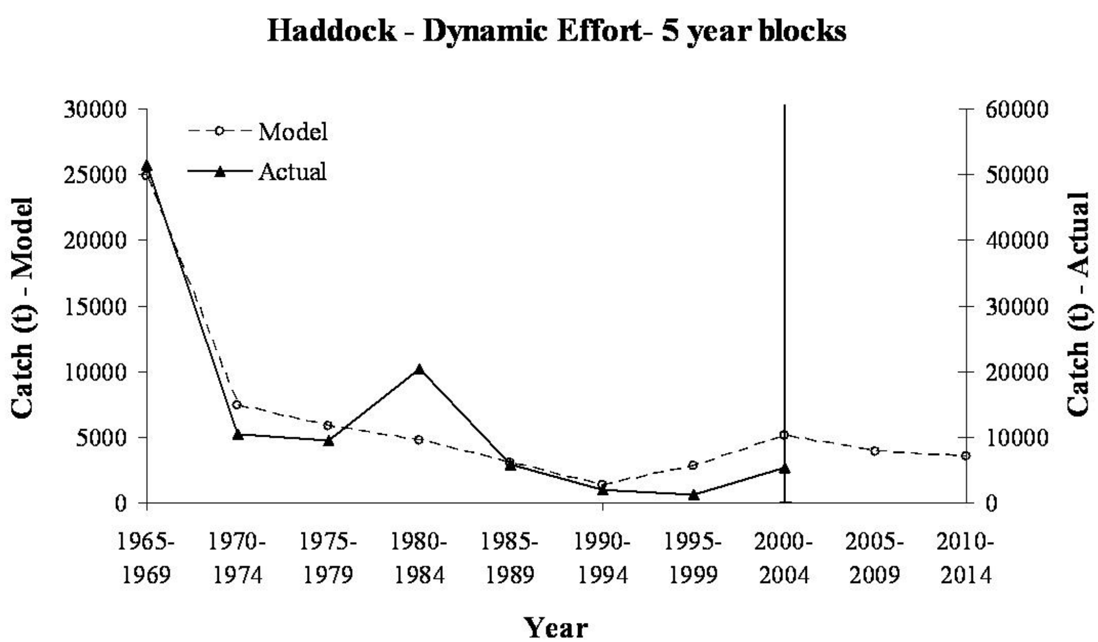
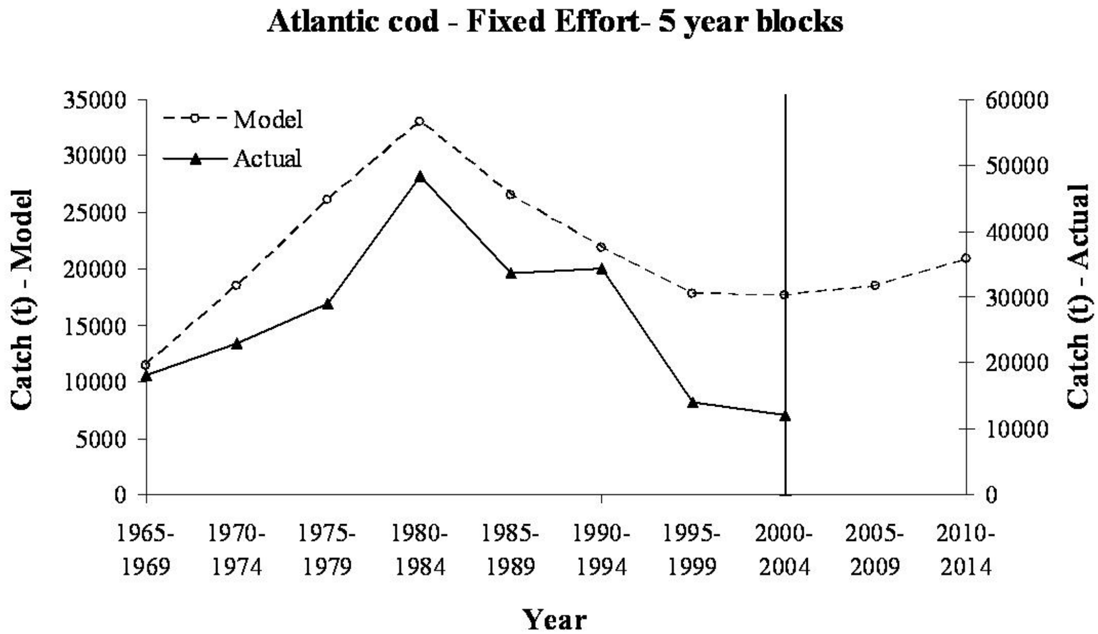


b.

Figure 12. Haddock (*Melanogrammus aeglefinus*) catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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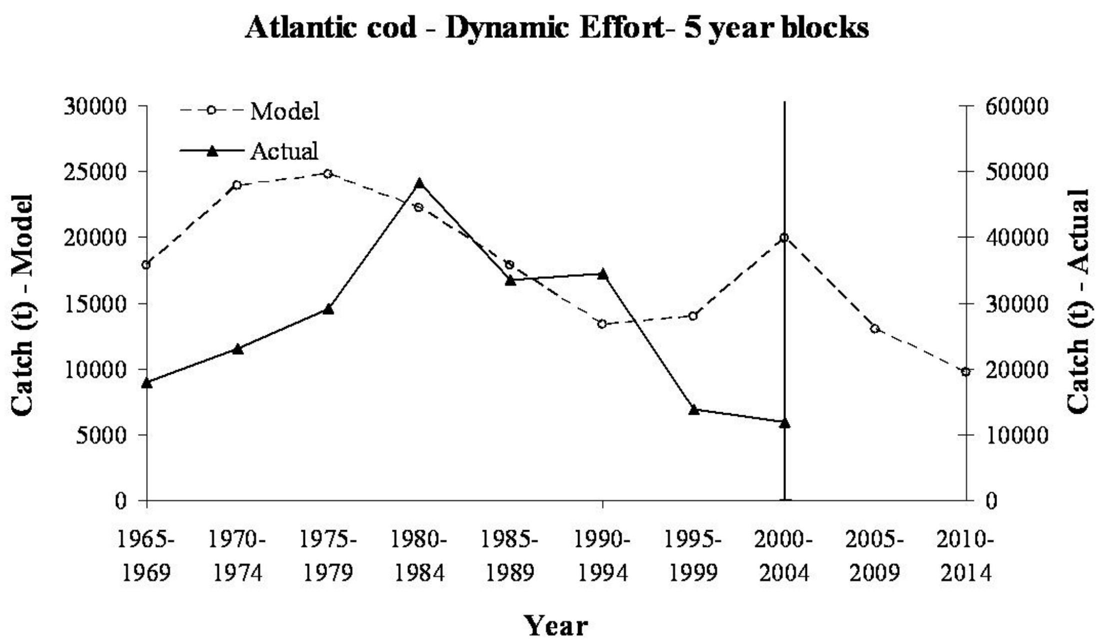

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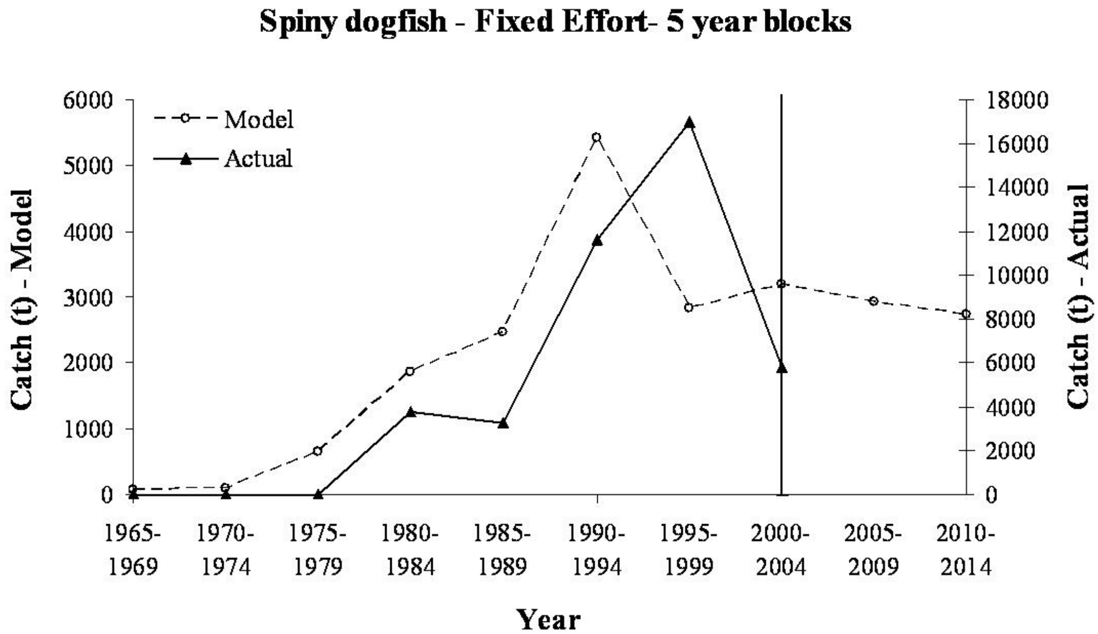
Figure 13. Atlantic cod (*Gadus morhua*) catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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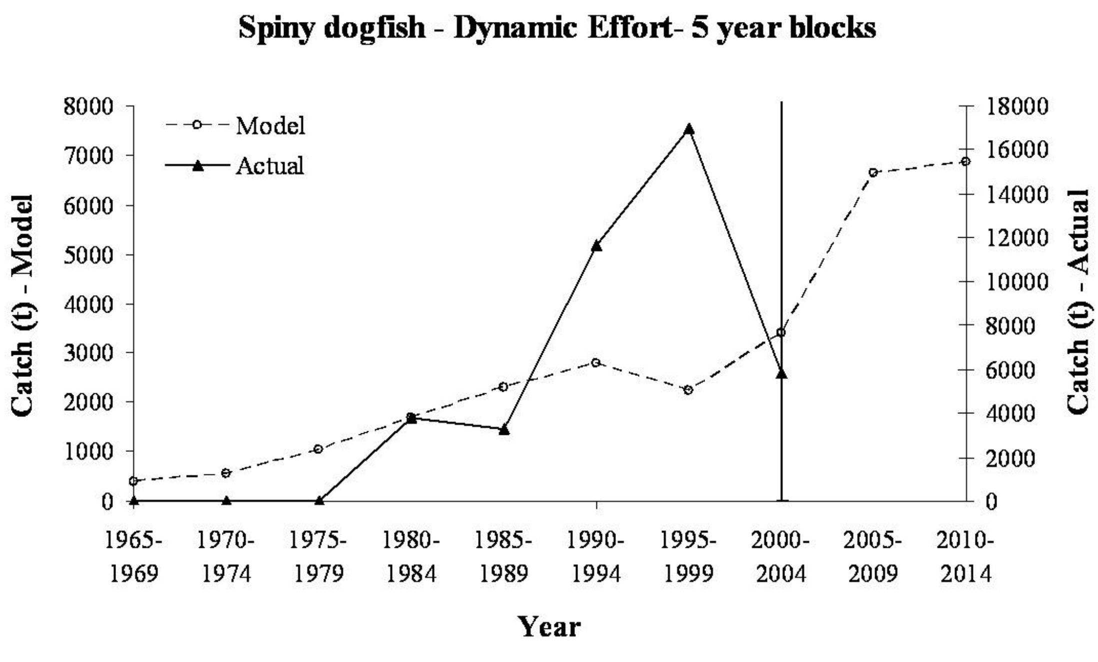
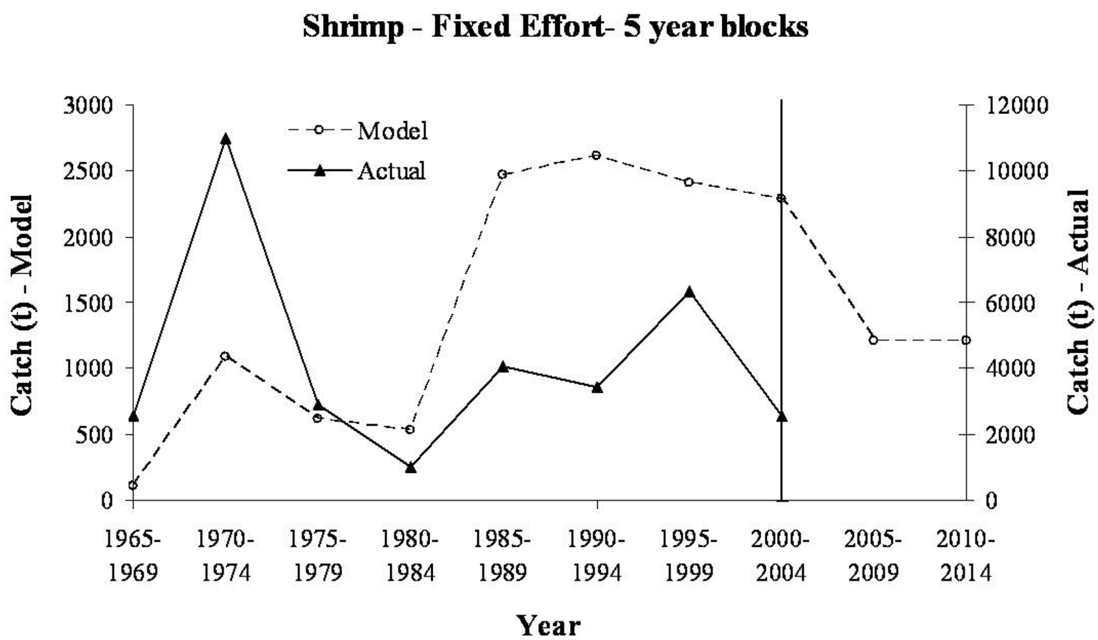


b.

Figure 14. Spiny dogfish (*Squalus acanthias*) catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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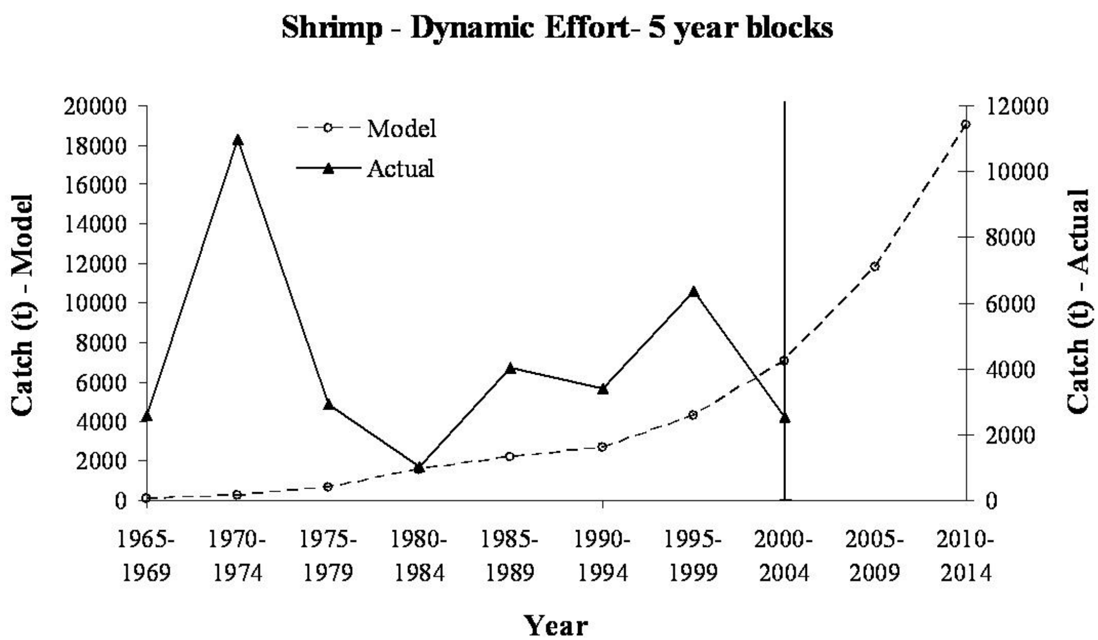


b.

Figure 15. Shrimp catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.

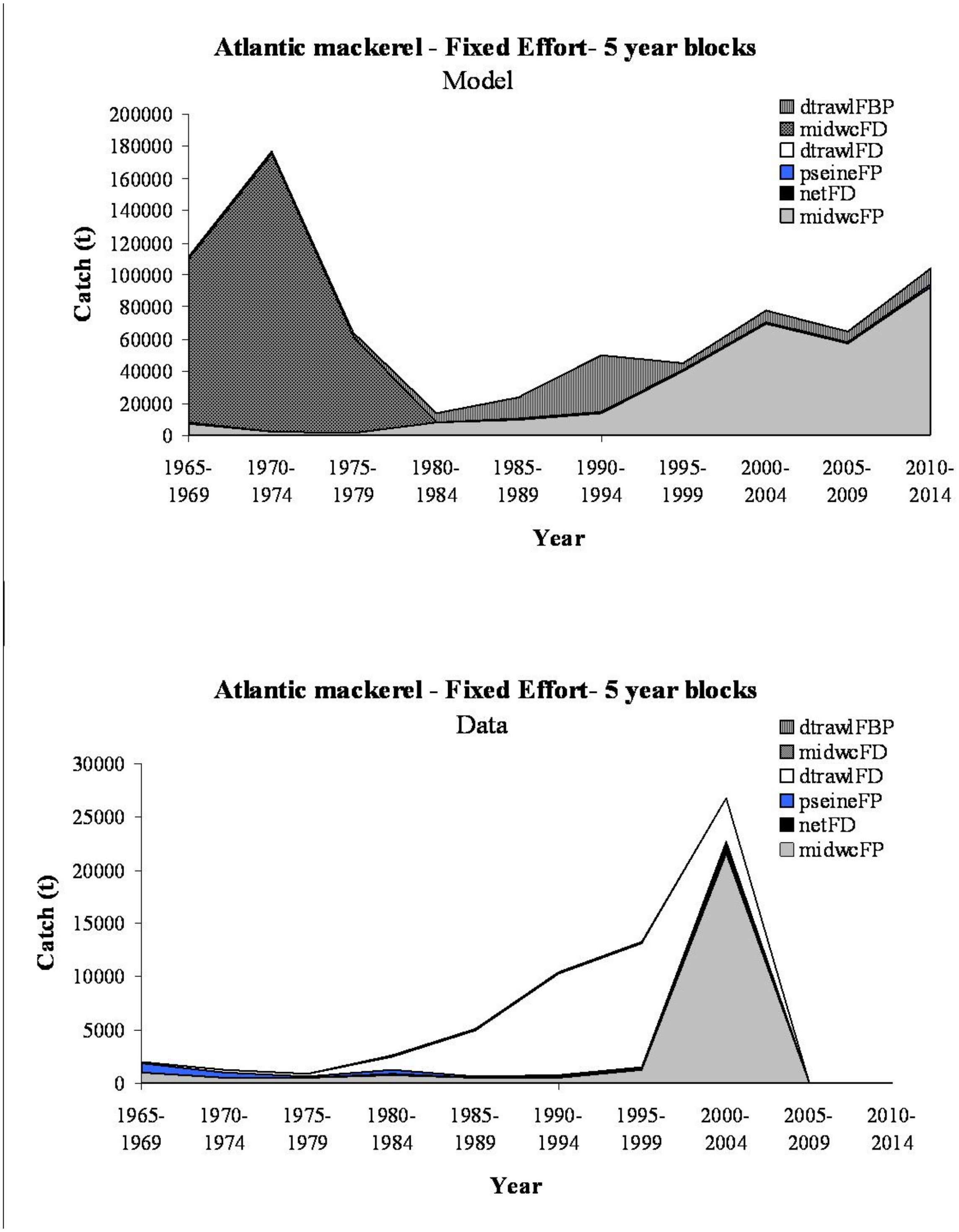
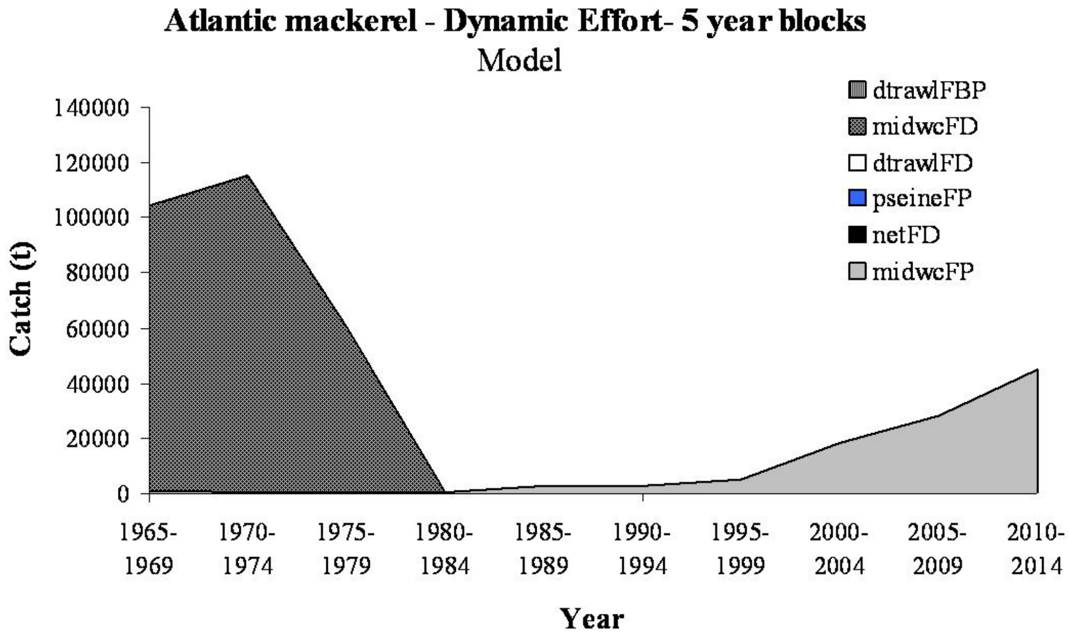


Figure 16. Atlantic mackerel (*Scomber scombrus*) catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



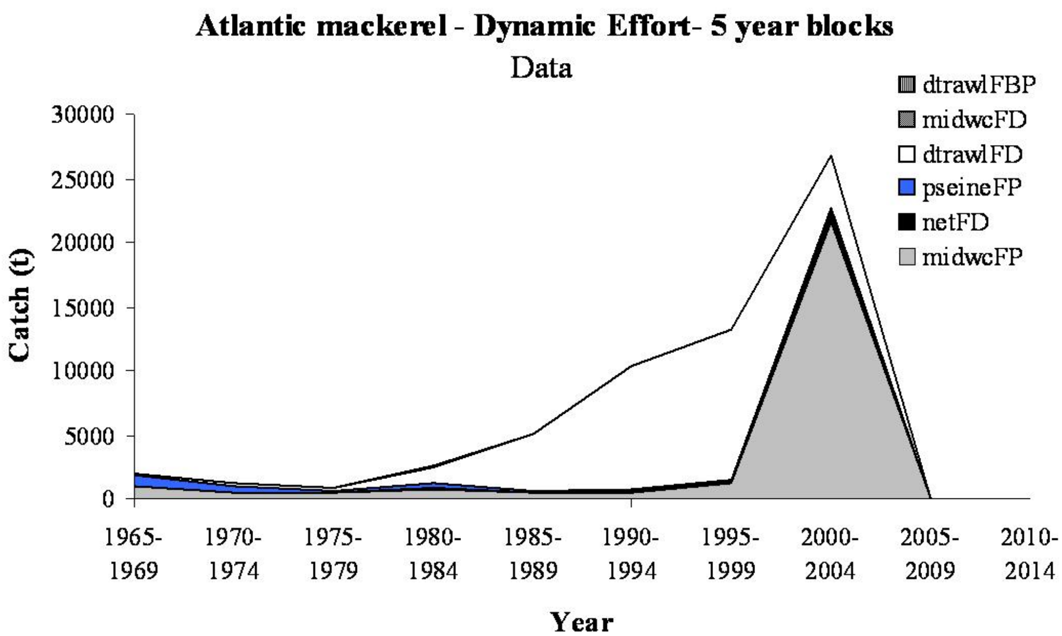
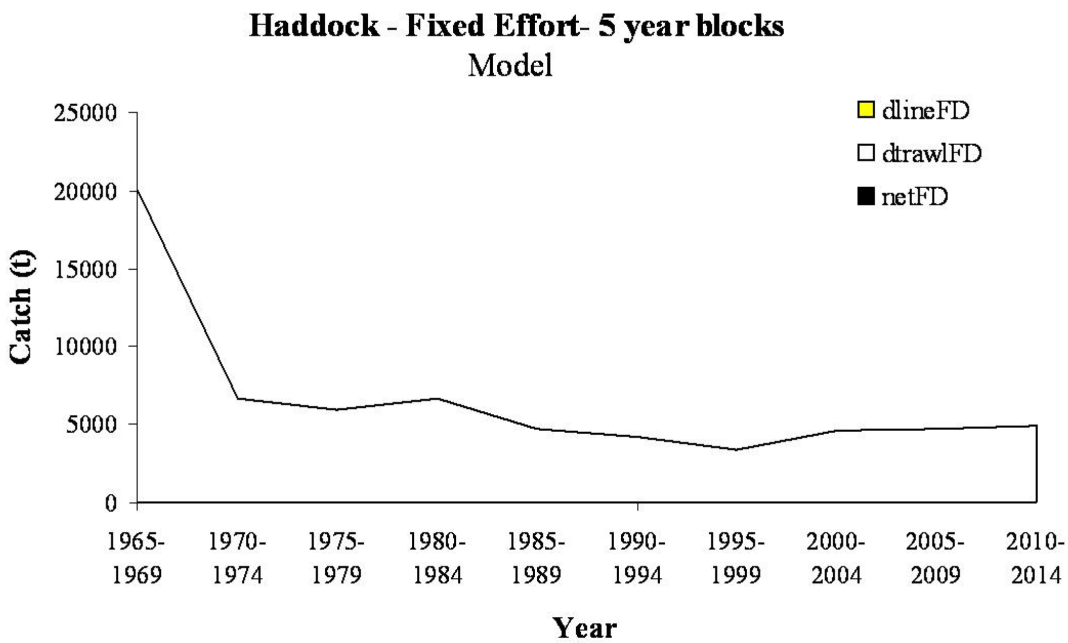


Figure 17. Atlantic mackerel (*Scomber scombrus*) catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



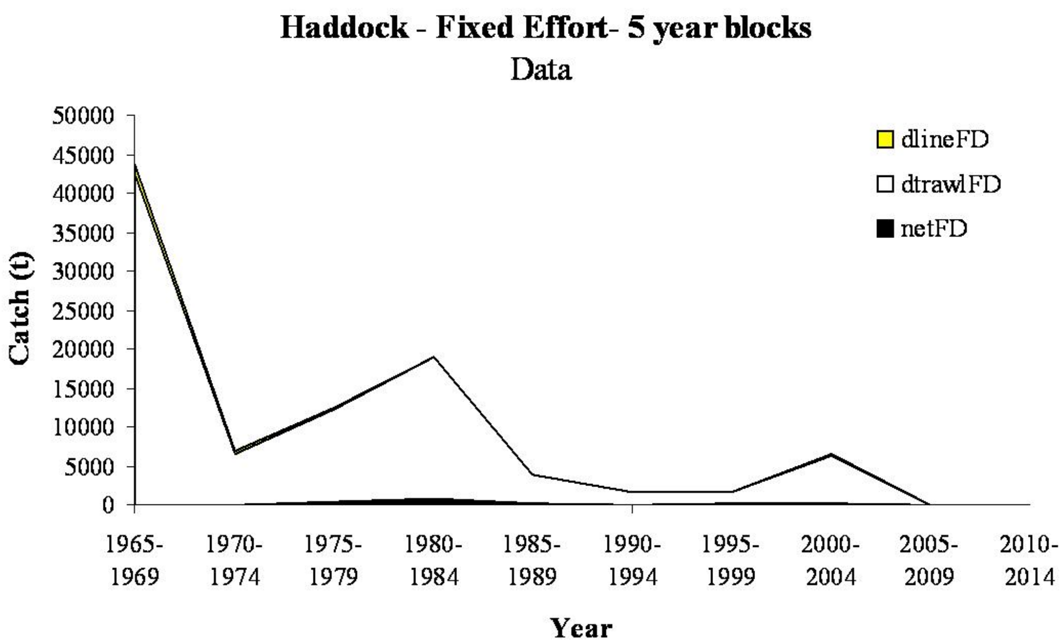
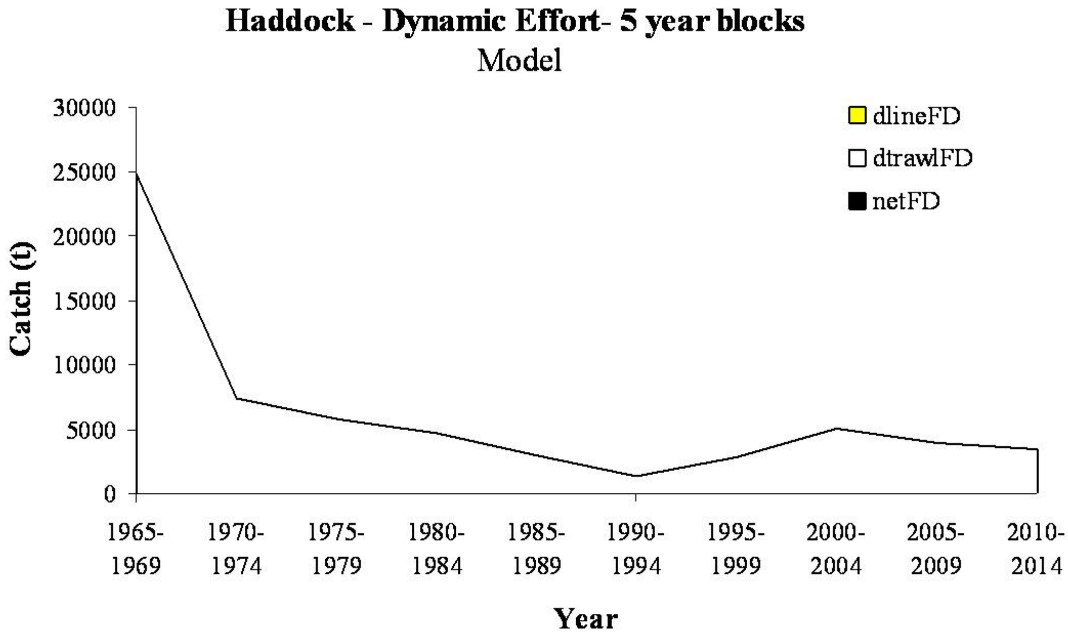


Figure 18. Haddock (*Melanogrammus aeglefinus*) catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



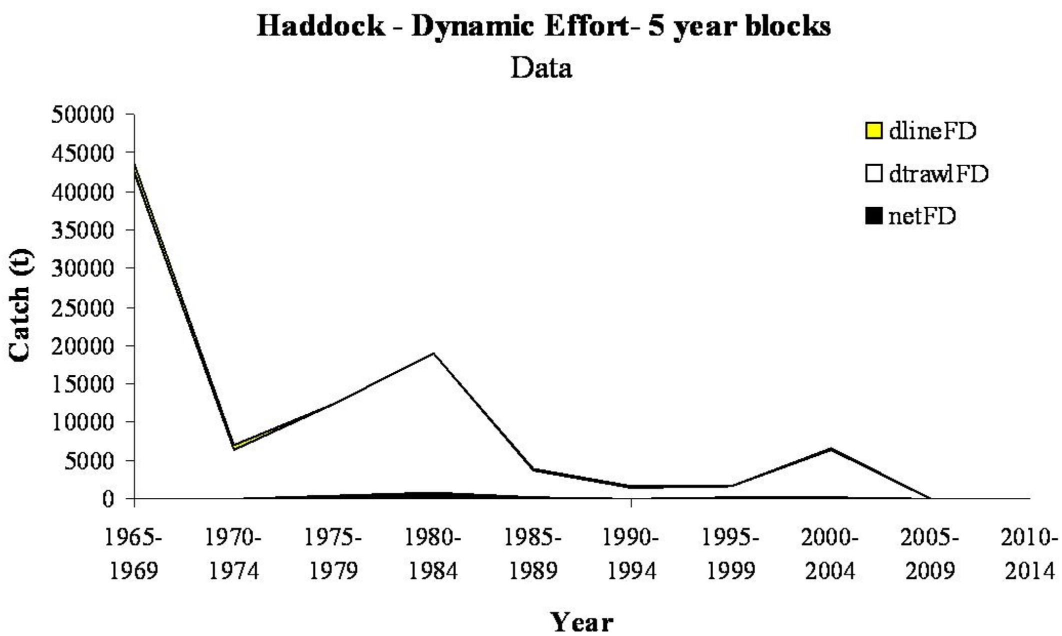
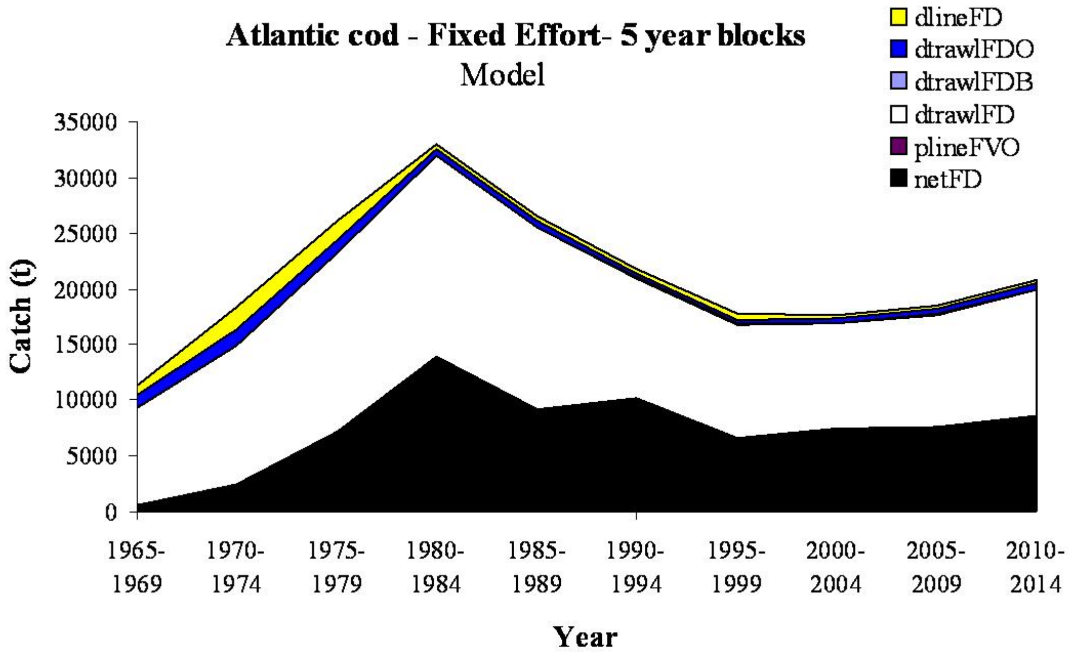


Figure 19. Haddock (*Melanogrammus aeglefinus*) catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



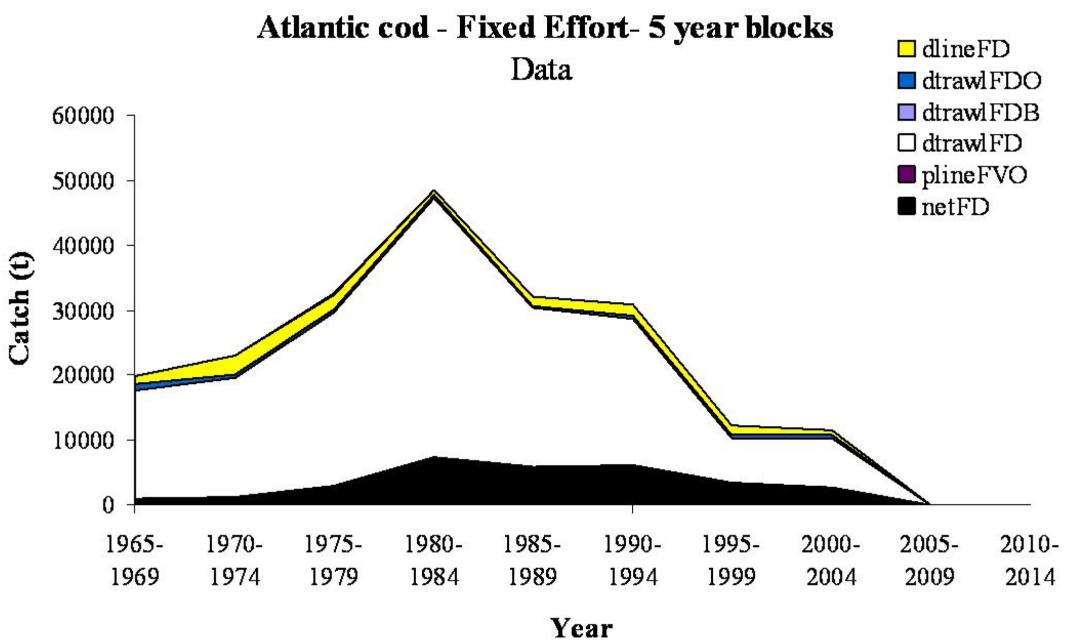
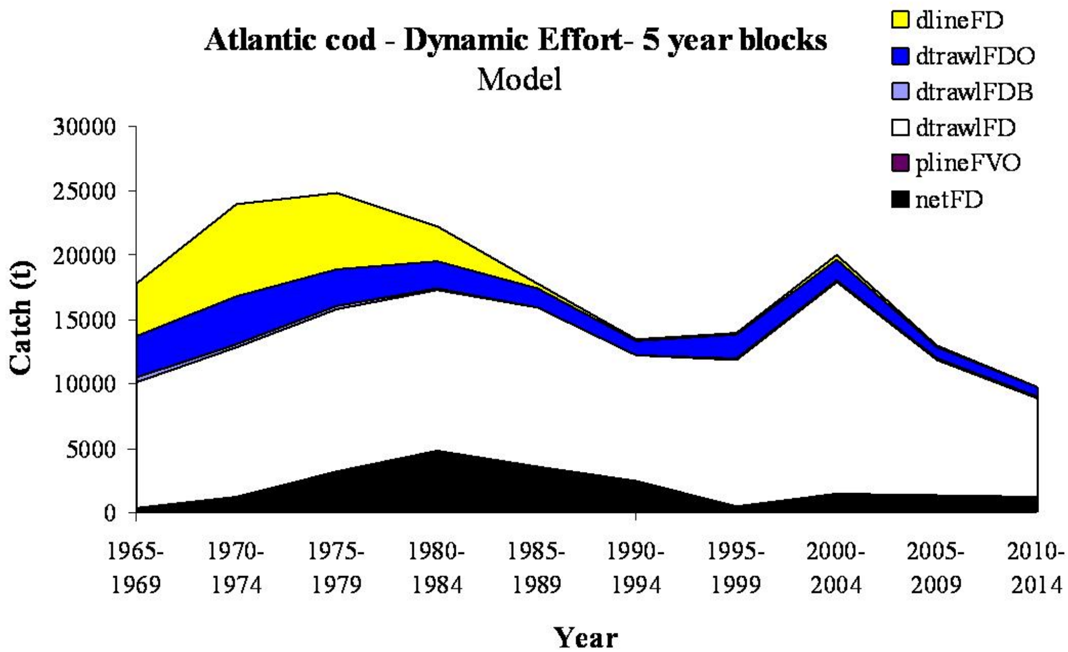


Figure 20. Atlantic cod (*Gadus morhua*) catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



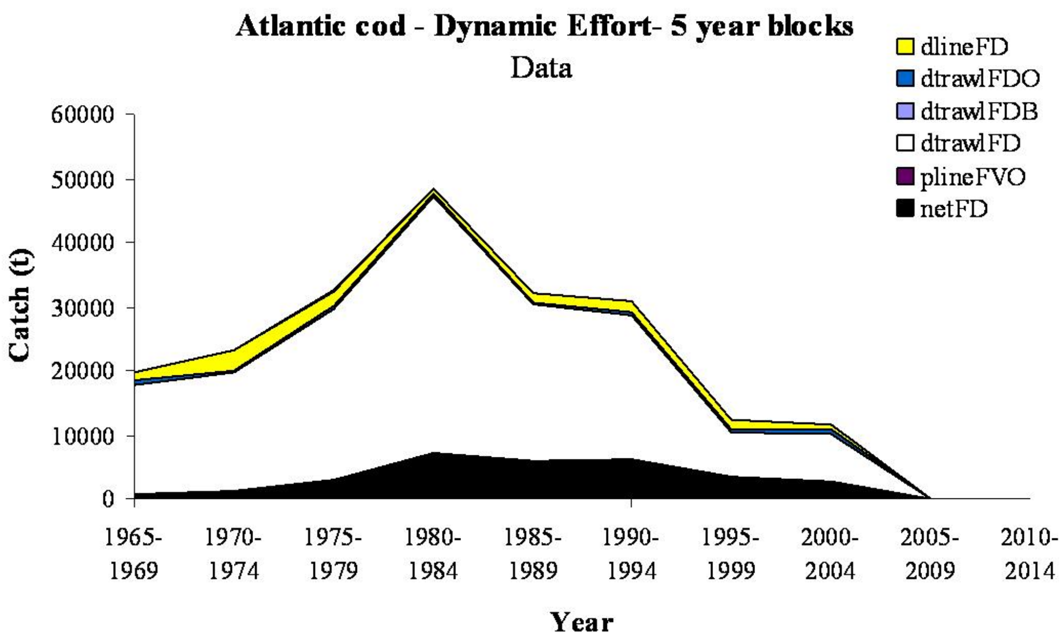
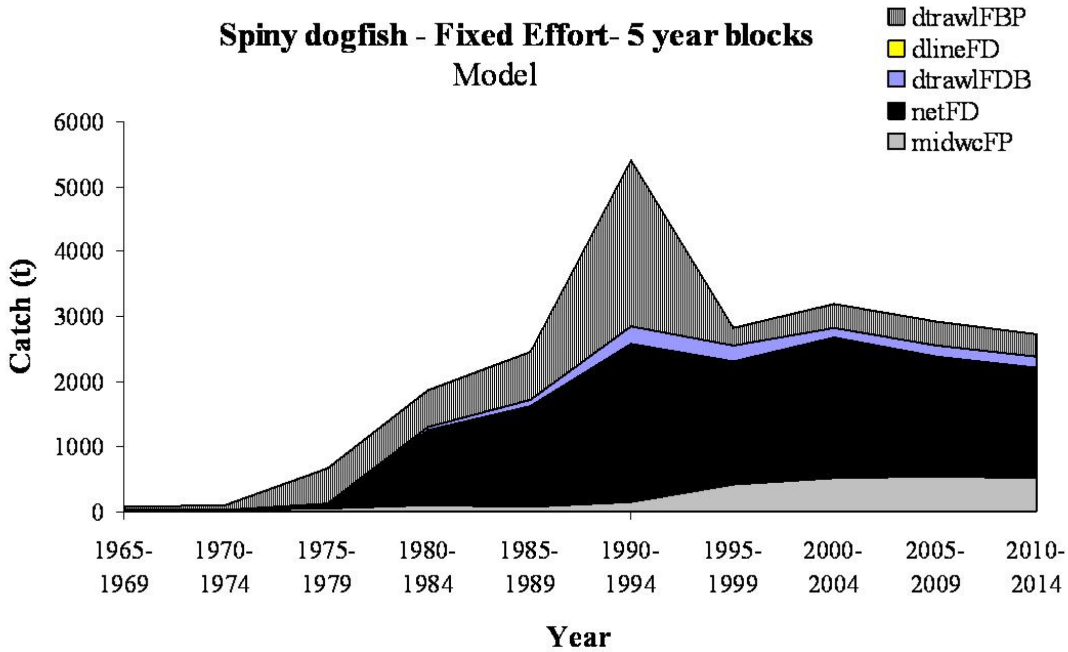


Figure 21. Atlantic cod (*Gadus morhua*) catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



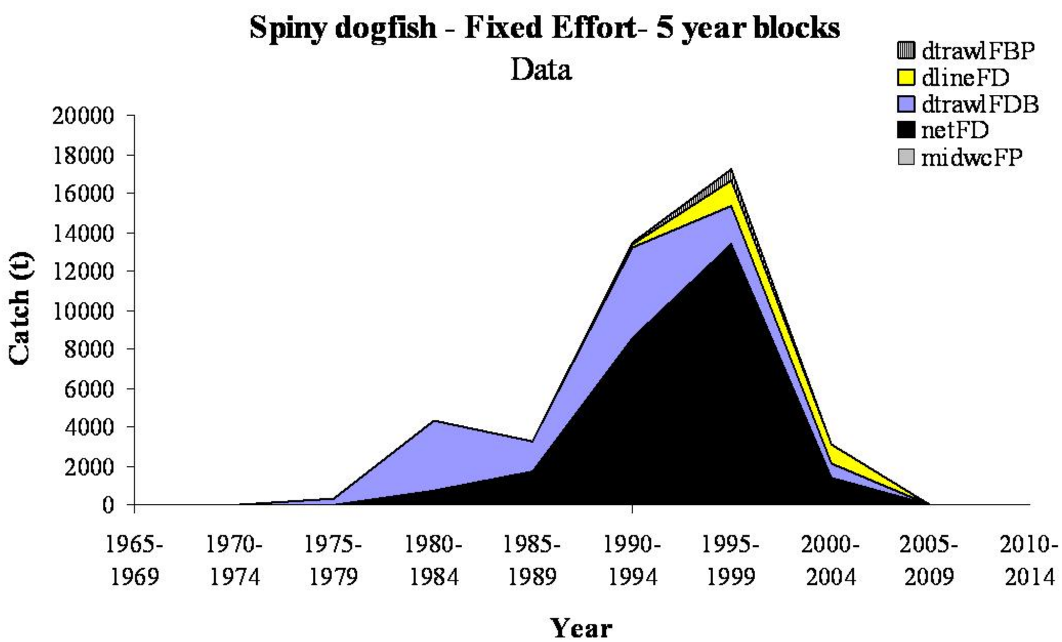
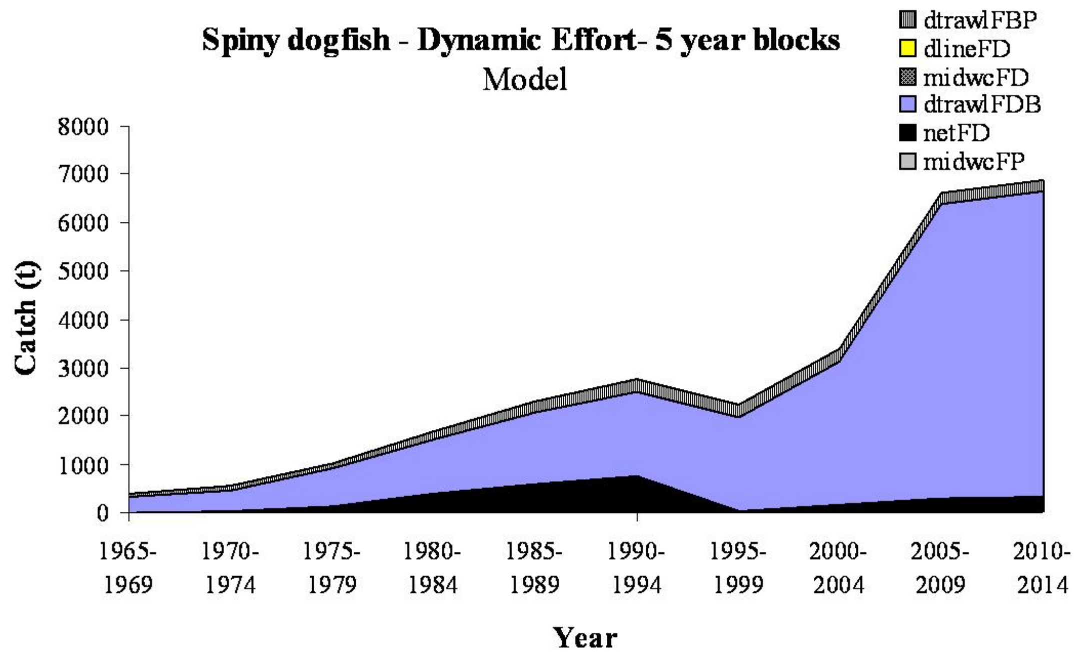


Figure 22. Spiny dogfish (*Squalus acanthias*) catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



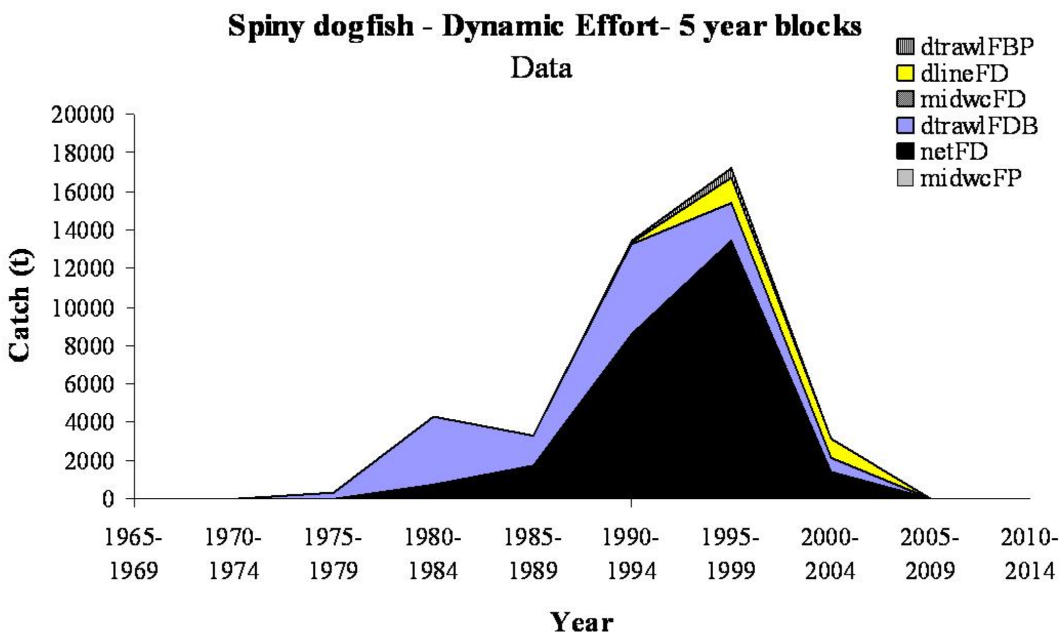
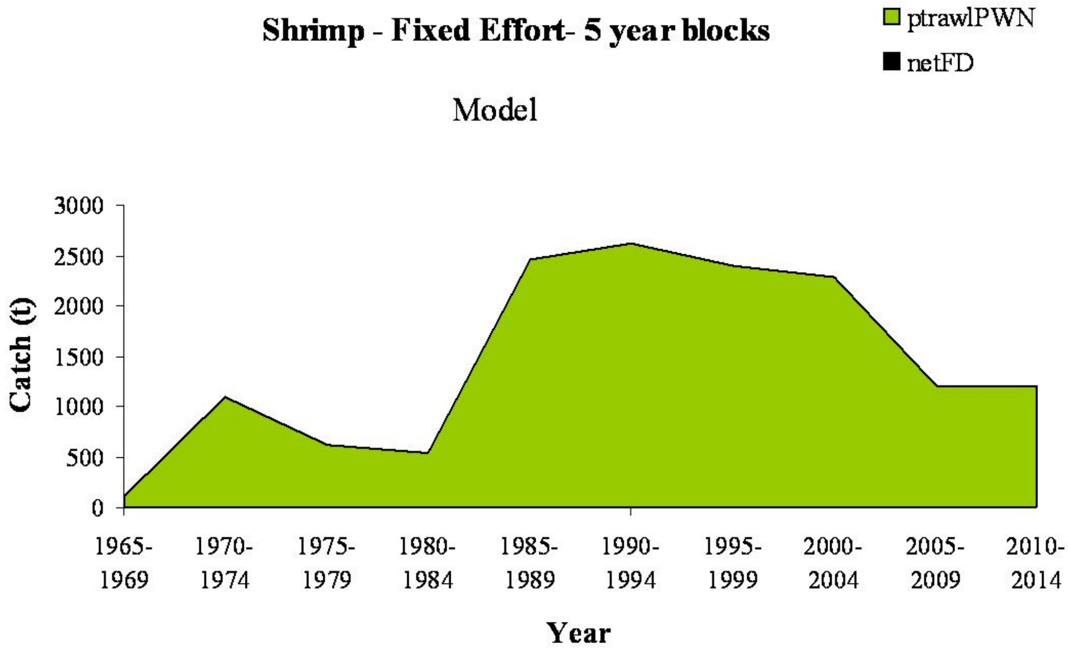


Figure 23. Spiny dogfish (*Squalus acanthias*) catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



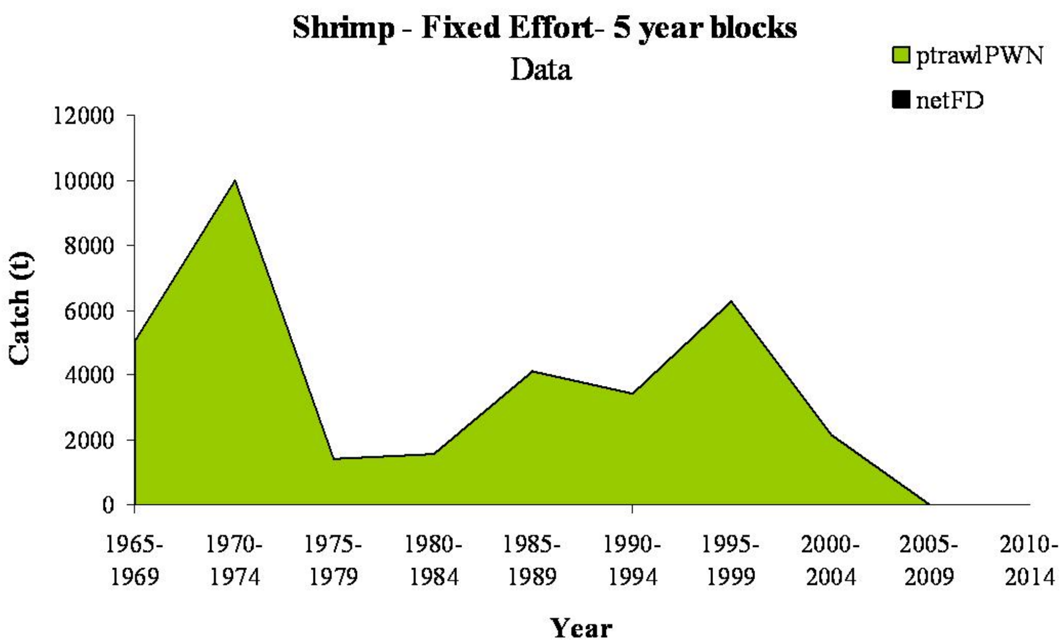
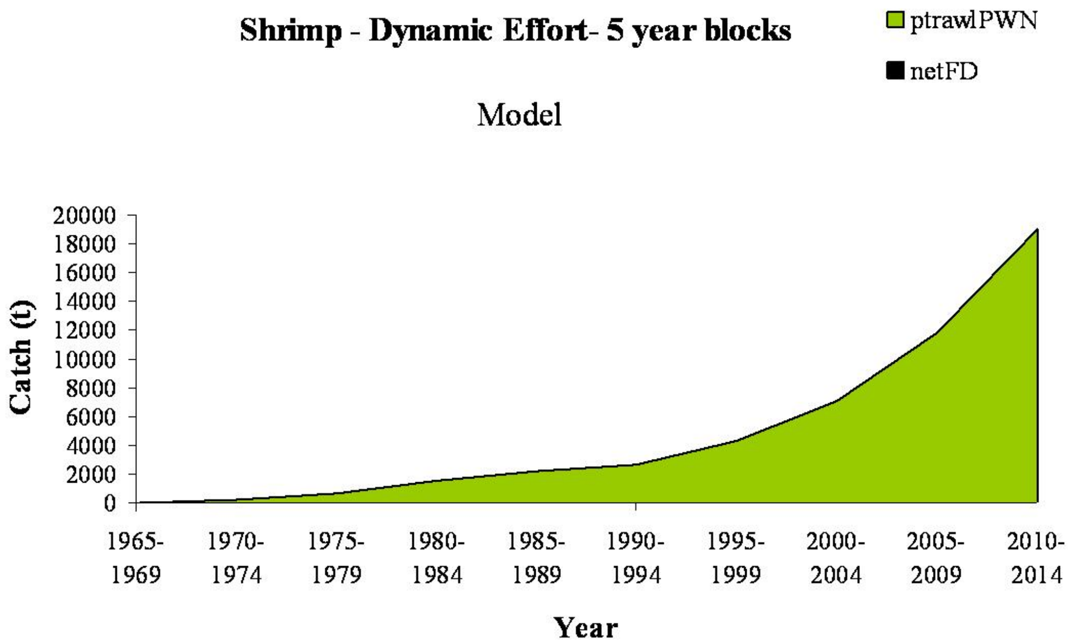


Figure 24. Shrimp catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



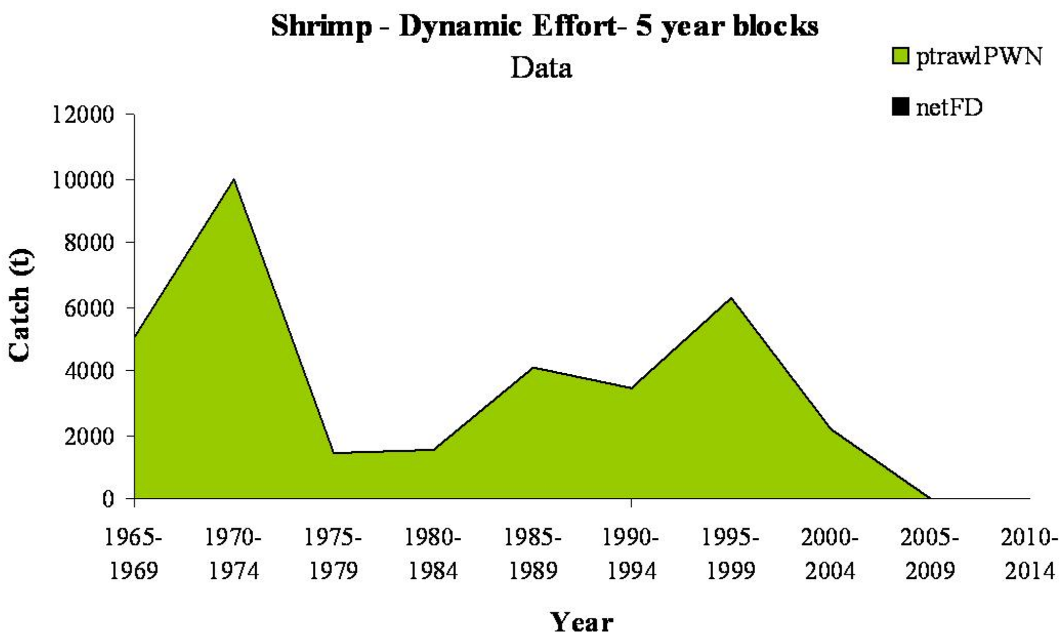


Figure 25. Shrimp catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

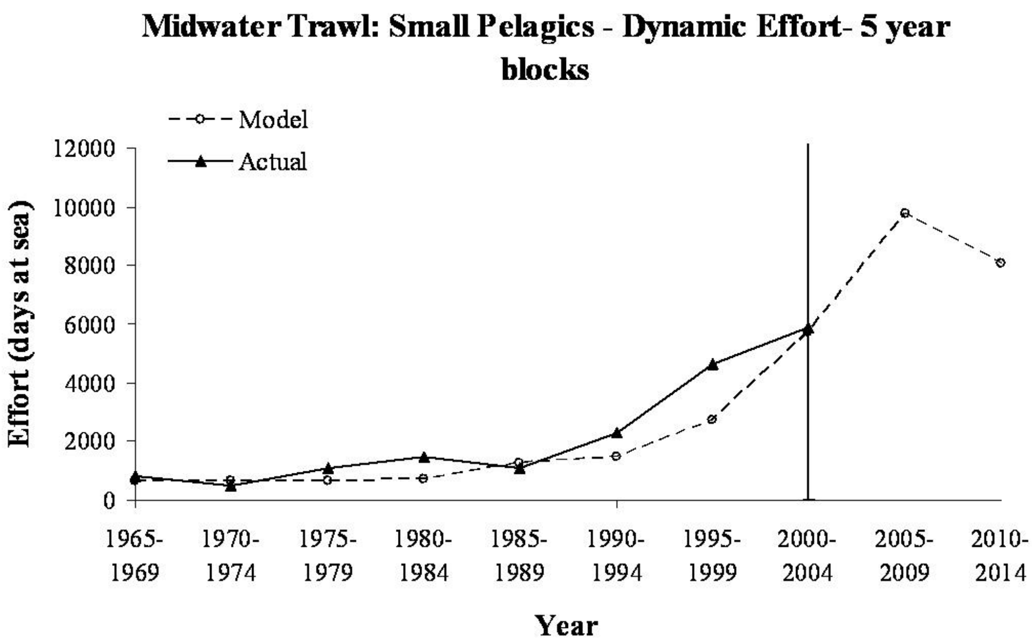


Figure 26. Effort trajectory for the midwater trawl on small pelagics for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

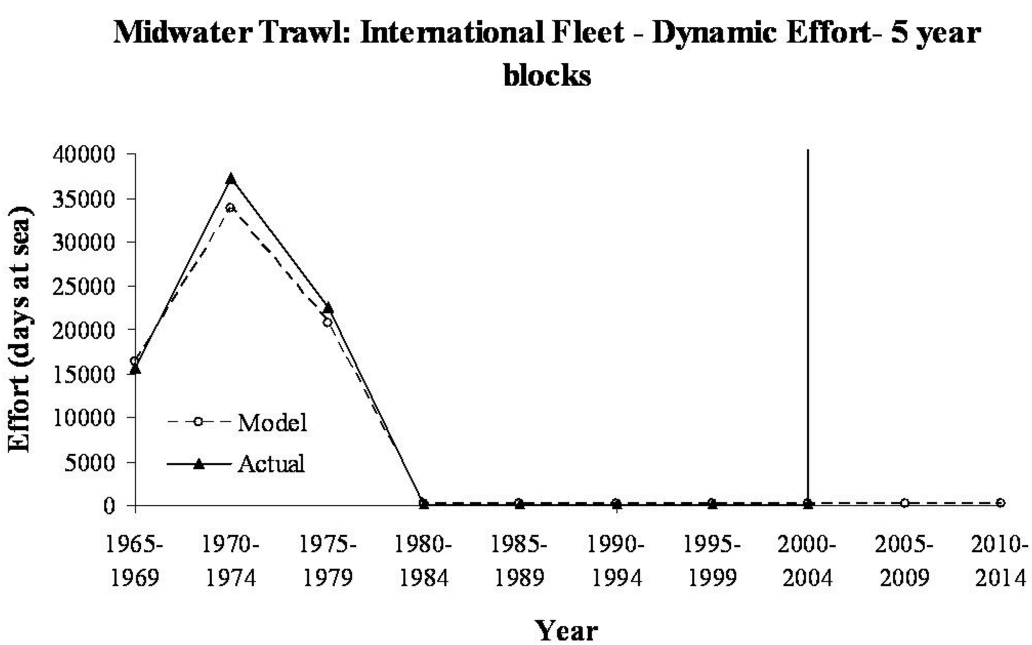


Figure 27. Effort trajectory for the international fleet - midwater trawl for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

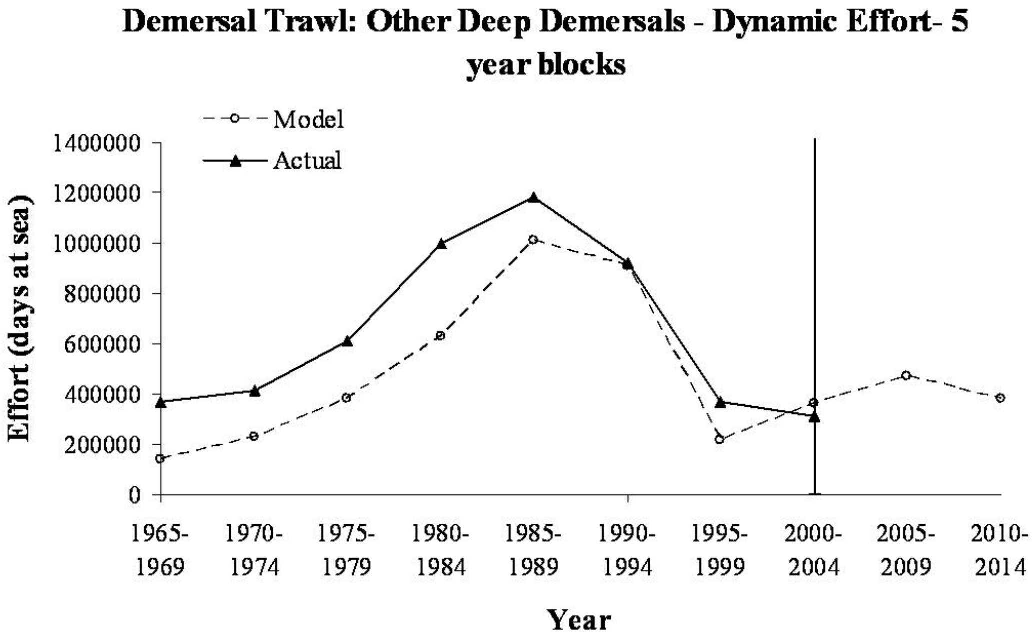


Figure 28. Effort trajectory for the demersal trawl on other deep demersals for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

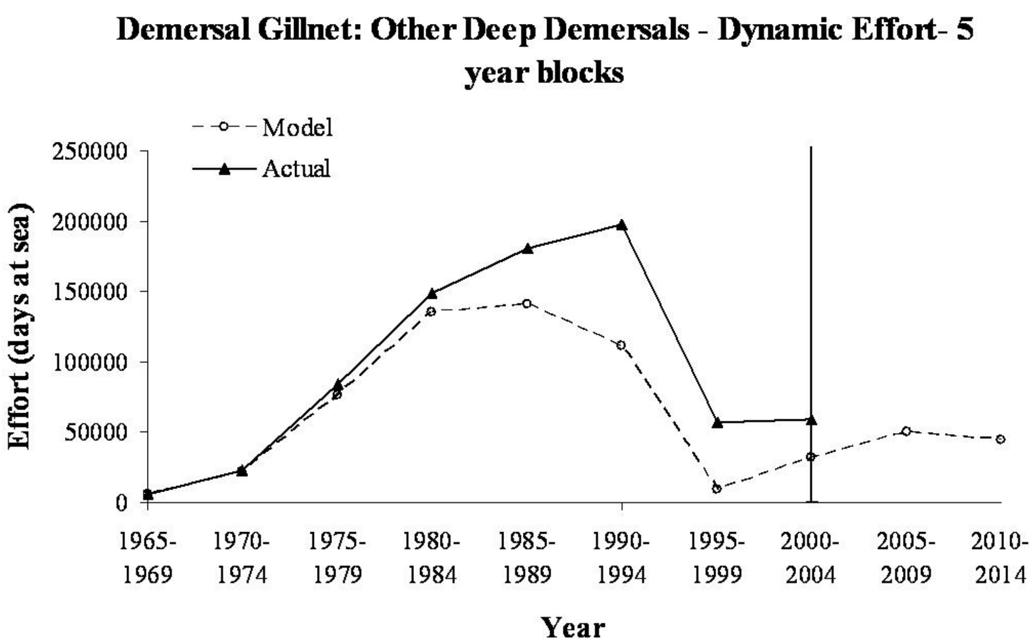


Figure 29. Effort trajectory for the demersal gillnet on other deep demersals for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

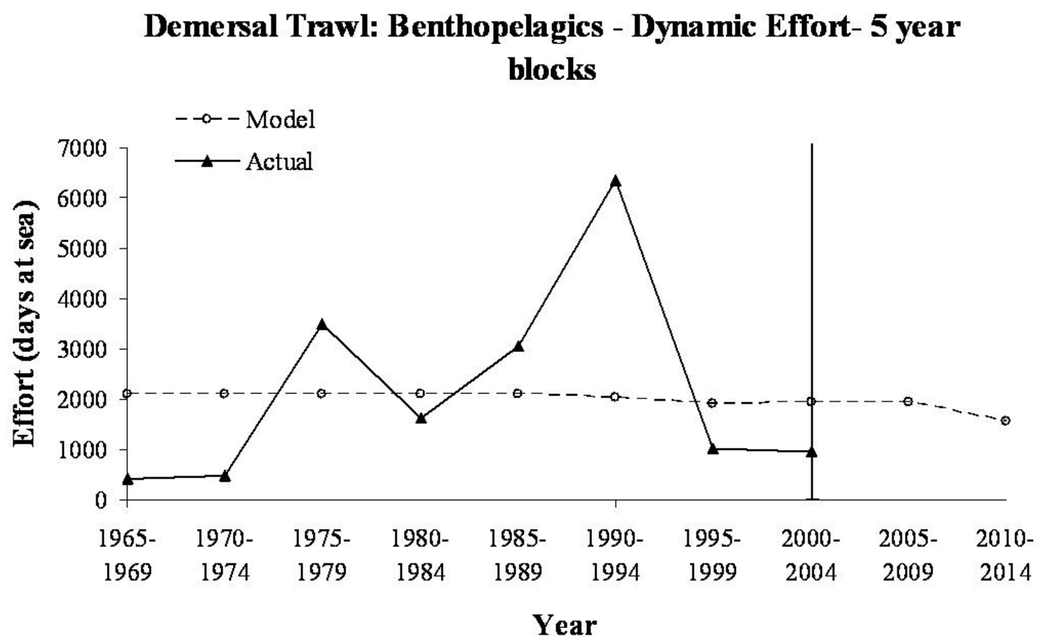


Figure 30. Effort trajectory for the demersal trawl on benthopelagics for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

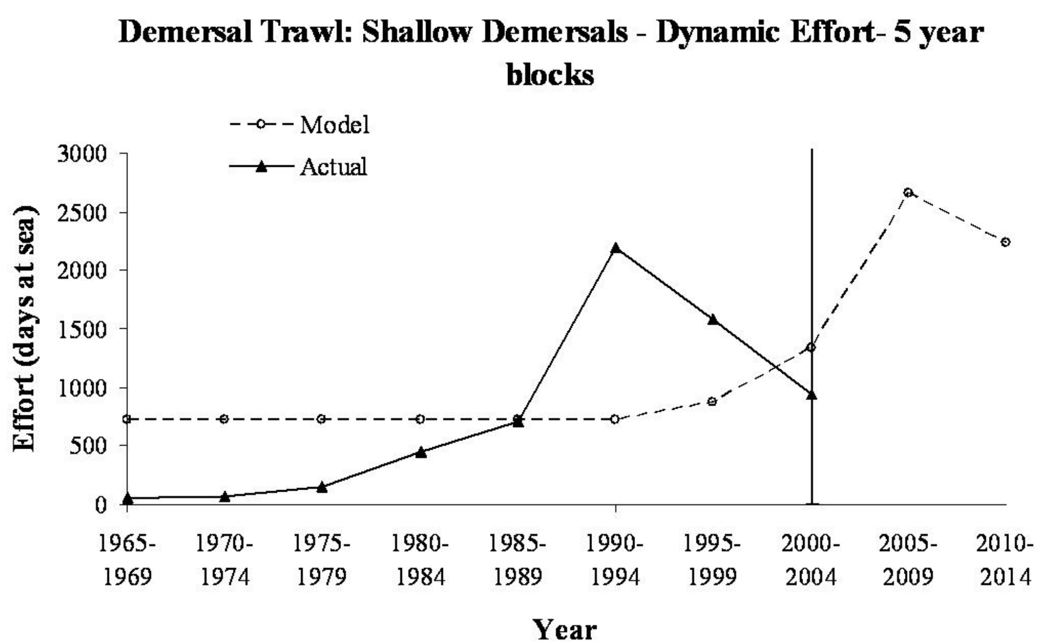


Figure 31. Effort trajectory for the demersal trawl on shallow demersals for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

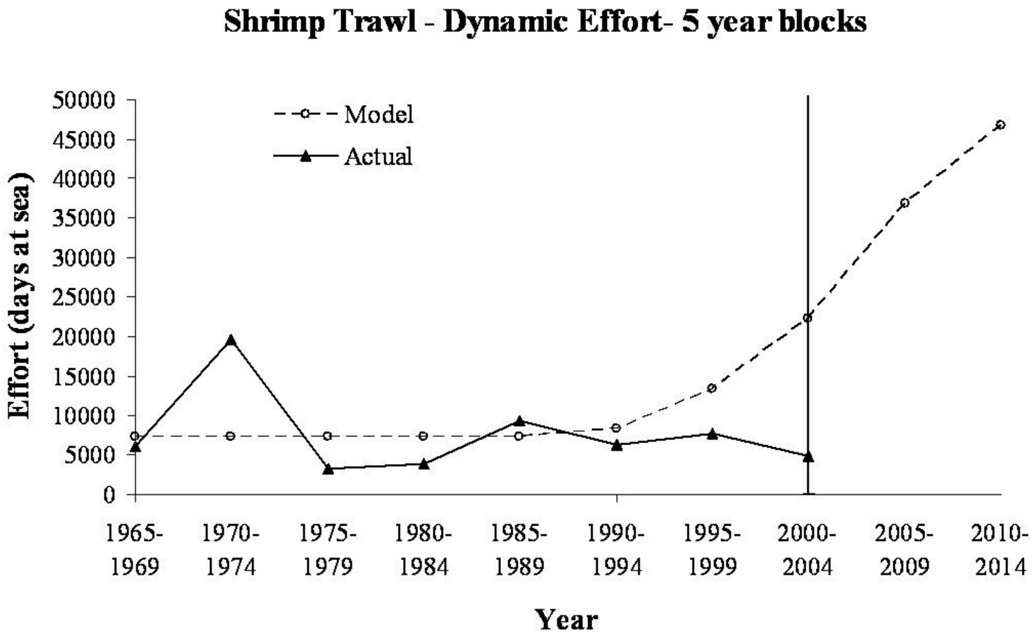


Figure 32. Effort trajectory for the shrimp trawl for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

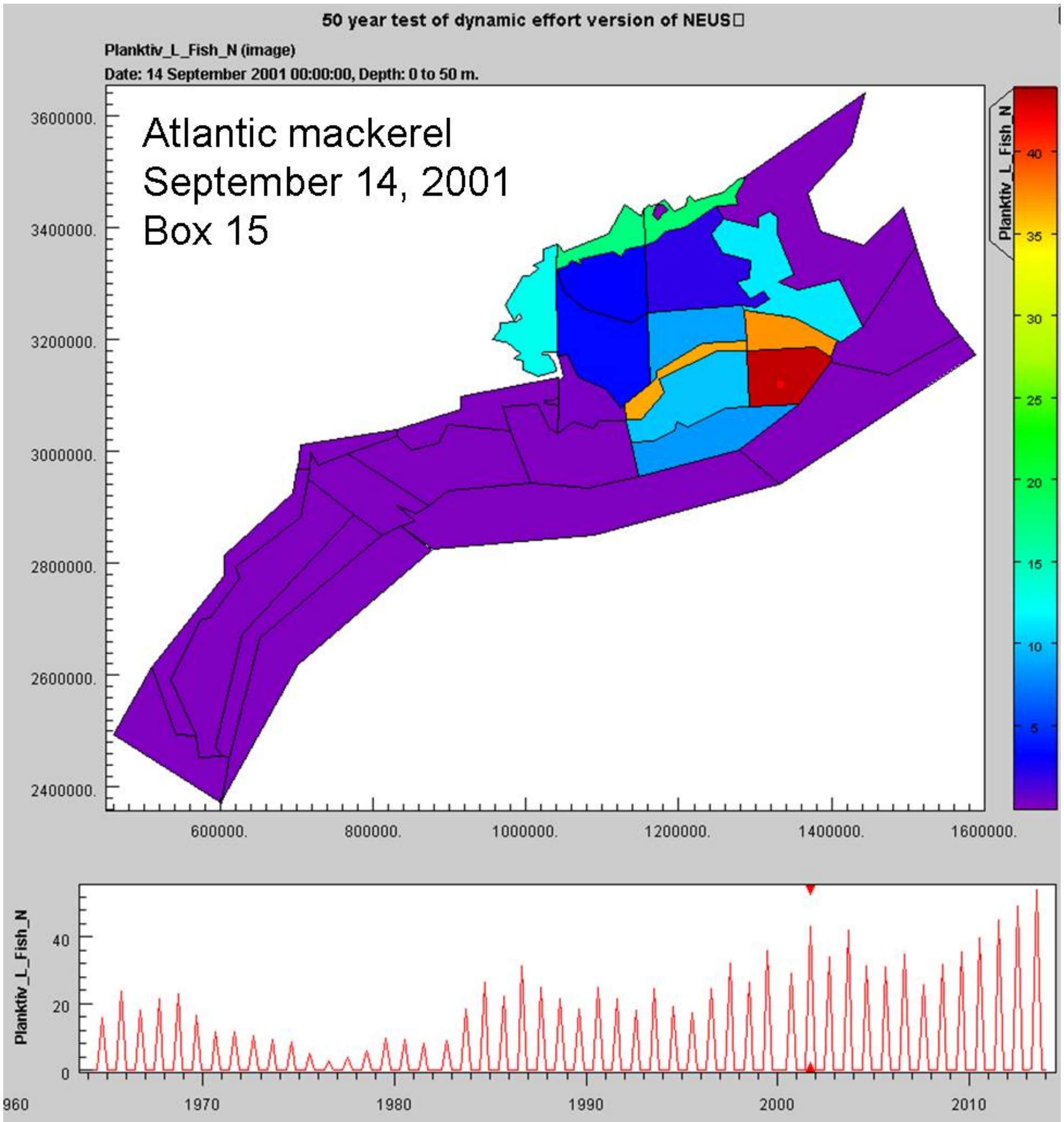


Figure 33. Atlantic mackerel (*Scomber scombrus*) spatial distribution on September 14, 2001 of the dynamic model run. The red dot indicates the currently selected box and the time series below shows the biomass in mt / km^2. Each box is indicated on the map, and the time series at the bottom shows abundance over the run of the model in the box indicated by the red dot on the map. The map itself shows the abundance at the specific time indicated in the upper left of the image (the time is also referenced with red triangles at the top and bottom of the time series). Cooler colors (blue, purple) on the map indicate lower abundance, while warmer colors (yellow, orange and red) indicate higher abundance.

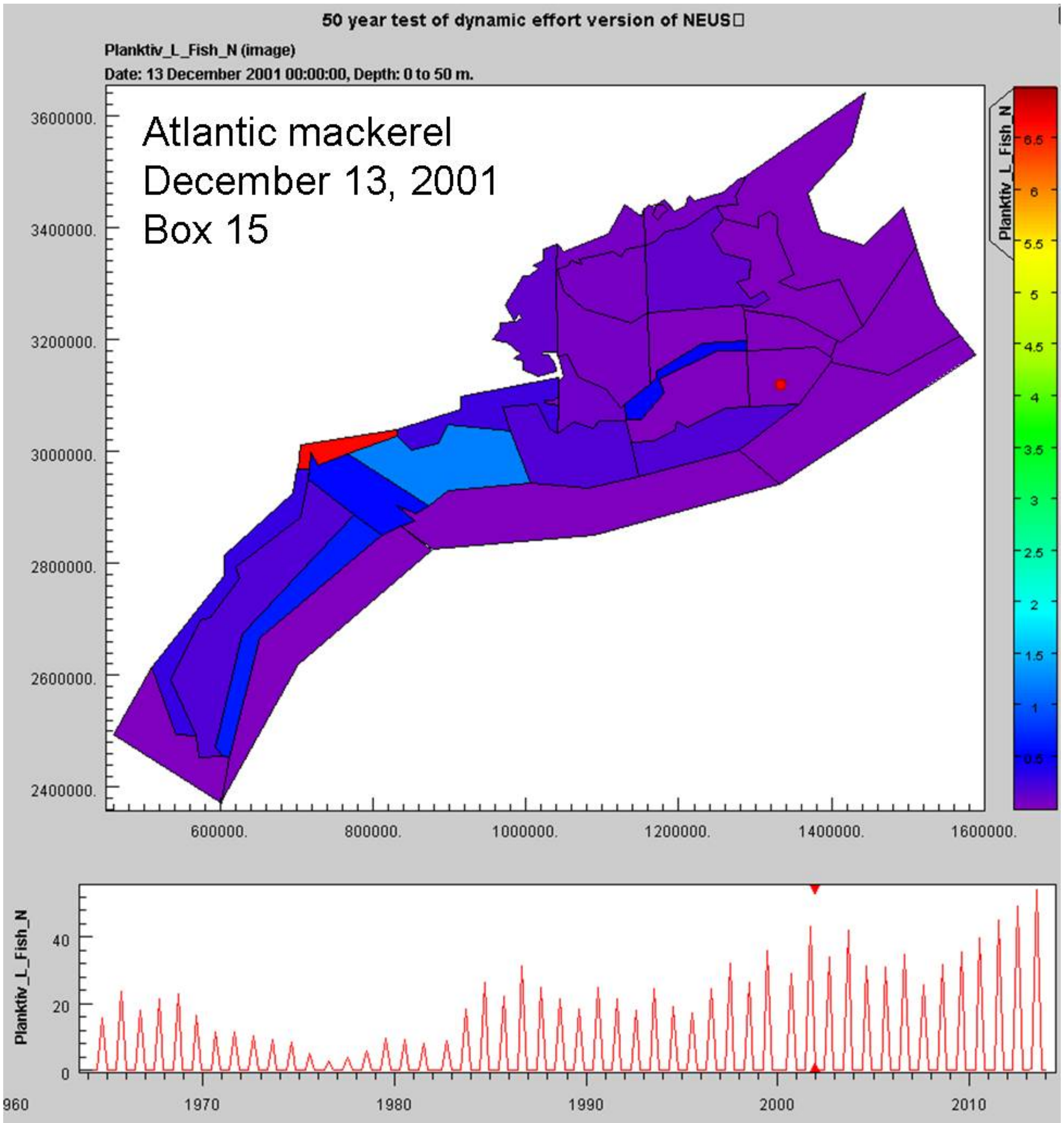


Figure 34. Atlantic mackerel (*Scomber scombrus*) spatial distribution on December 13, 2001 of the dynamic model run. The red dot indicates the currently selected box and the time series below shows the biomass in mt / km^2. The dramatic change in distribution compared to Figure 33 is due to seasonal migrations built into the model. Each box is indicated on the map, and the time series at the bottom shows abundance over the run of the model in the box indicated by the red dot on the map. The map itself shows the abundance at the specific time indicated in the upper left of the image (the time is also referenced with red triangles at the top and bottom of the time series). Cooler colors (blue, purple) on the map indicate lower abundance, while warmer colors (yellow, orange and red) indicate higher abundance.

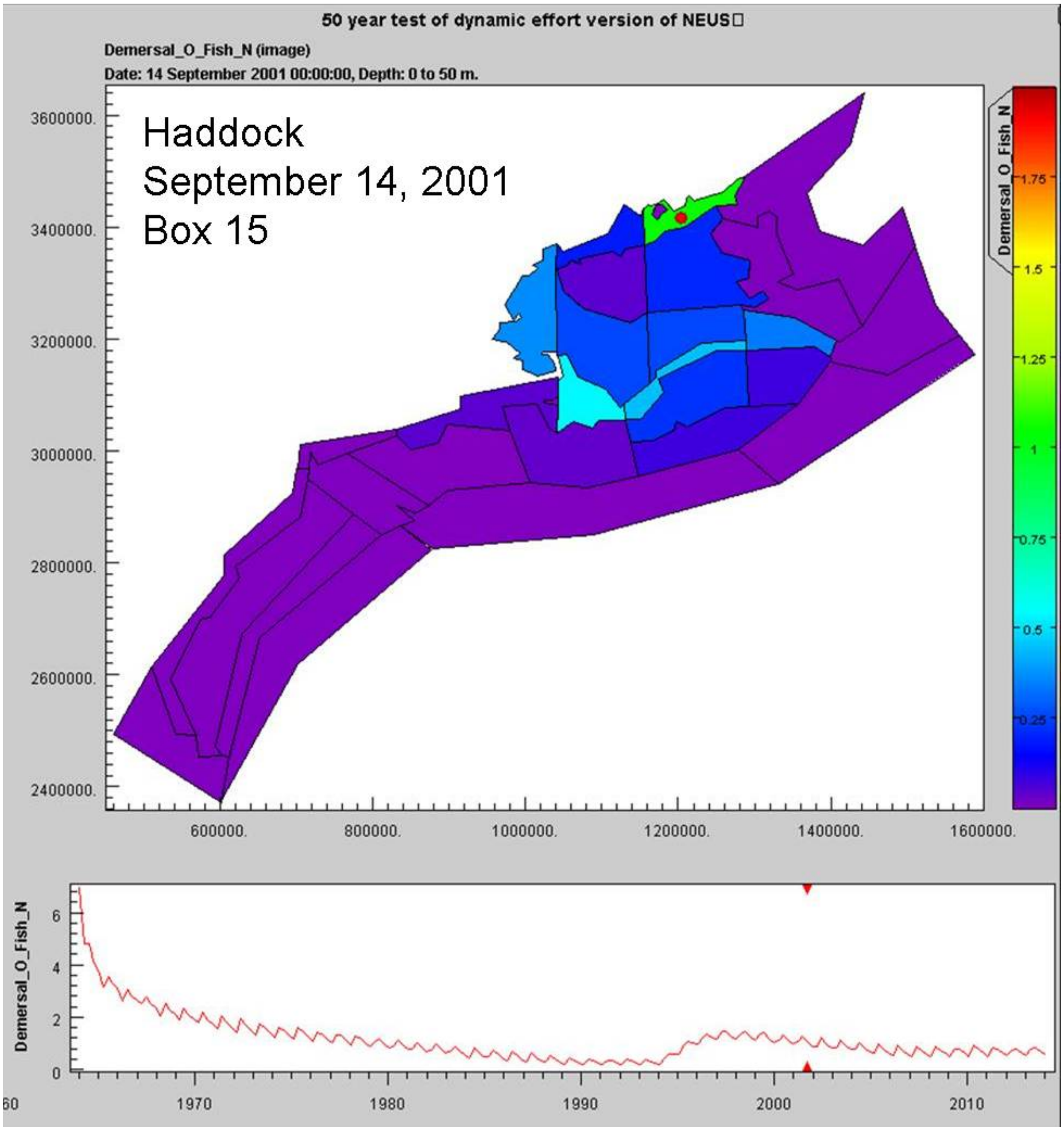


Figure 35. Haddock (*Melanogrammus aeglefinus*) spatial distribution on September 14, 2001 of the dynamic model run. The red dot indicates the currently selected box and the time series below shows the biomass in mt / km^2. Each box is indicated on the map, and the time series at the bottom shows abundance over the run of the model in the box indicated by the red dot on the map. The map itself shows the abundance at the specific time indicated in the upper left of the image (the time is also referenced with red triangles at the top and bottom of the time series). Cooler colors (blue, purple) on the map indicate lower abundance, while warmer colors (yellow, orange and red) indicate higher abundance.

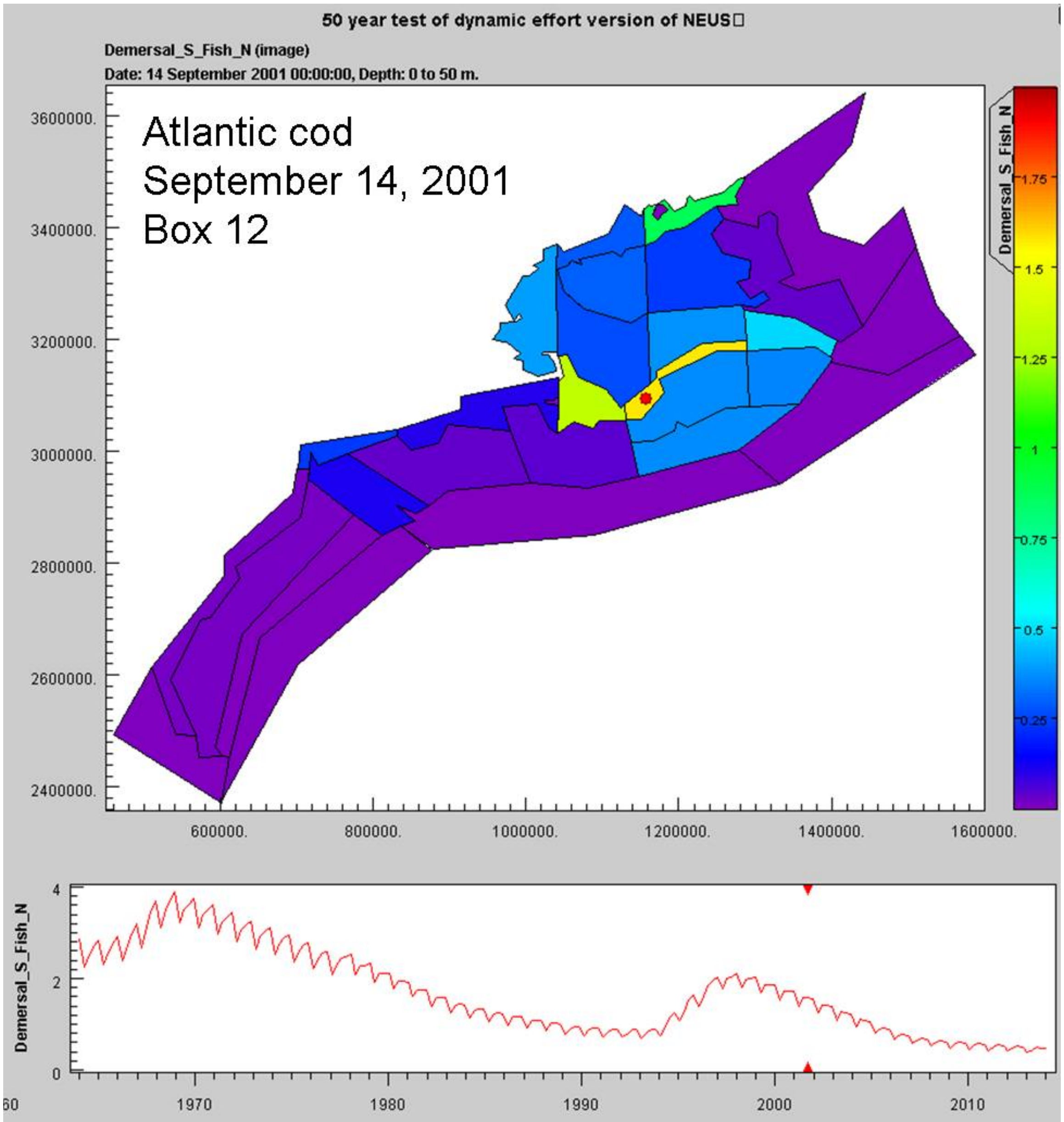


Figure 36. Atlantic cod (*Gadus morhua*) spatial distribution on September 14, 2001 of the dynamic model run. The red dot indicates the currently selected box and the time series below shows the biomass in mt / km^2. Each box is indicated on the map, and the time series at the bottom shows abundance over the run of the model in the box indicated by the red dot on the map. The map itself shows the abundance at the specific time indicated in the upper left of the image (the time is also referenced with red triangles at the top and bottom of the time series). Cooler colors (blue, purple) on the map indicate lower abundance, while warmer colors (yellow, orange and red) indicate higher abundance.

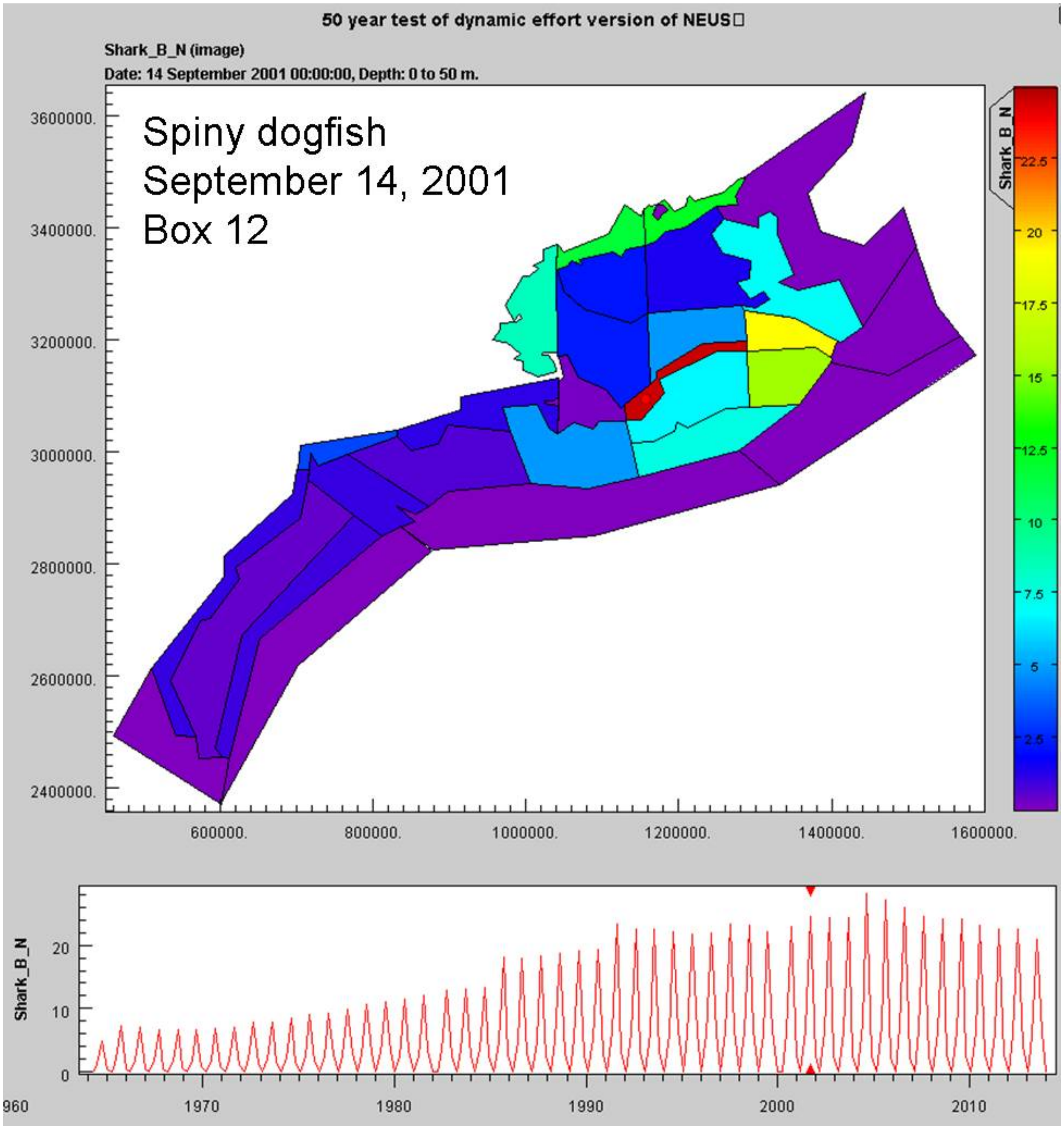


Figure 37. Spiny dogfish (*Squalus acanthias*) spatial distribution on September 14, 2001 of the dynamic model run. The red dot indicates the currently selected box and the time series below shows the biomass in mt / km^2. Each box is indicated on the map, and the time series at the bottom shows abundance over the run of the model in the box indicated by the red dot on the map. The map itself shows the abundance at the specific time indicated in the upper left of the image (the time is also referenced with red triangles at the top and bottom of the time series). Cooler colors (blue, purple) on the map indicate lower abundance, while warmer colors (yellow, orange and red) indicate higher abundance.

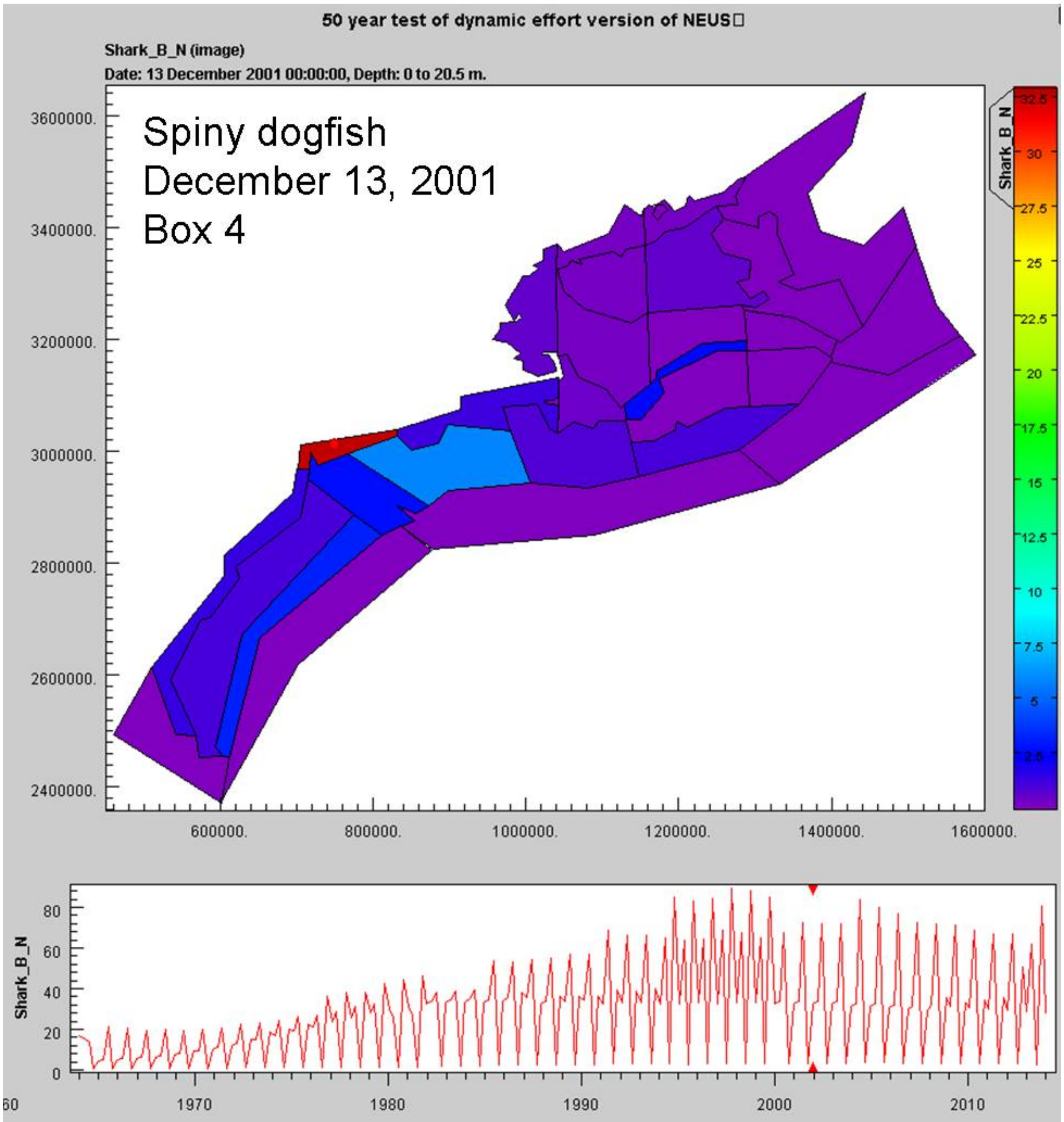


Figure 38. Spiny dogfish (*Squalus acanthias*) spatial distribution on December 13, 2001 of the dynamic model run. The red dot indicates the currently selected box and the time series below shows the biomass in mt / km^2. Each box is indicated on the map, and the time series at the bottom shows abundance over the run of the model in the box indicated by the red dot on the map. The map itself shows the abundance at the specific time indicated in the upper left of the image (the time is also referenced with red triangles at the top and bottom of the time series). Cooler colors (blue, purple) on the map indicate lower abundance, while warmer colors (yellow, orange and red) indicate higher abundance.

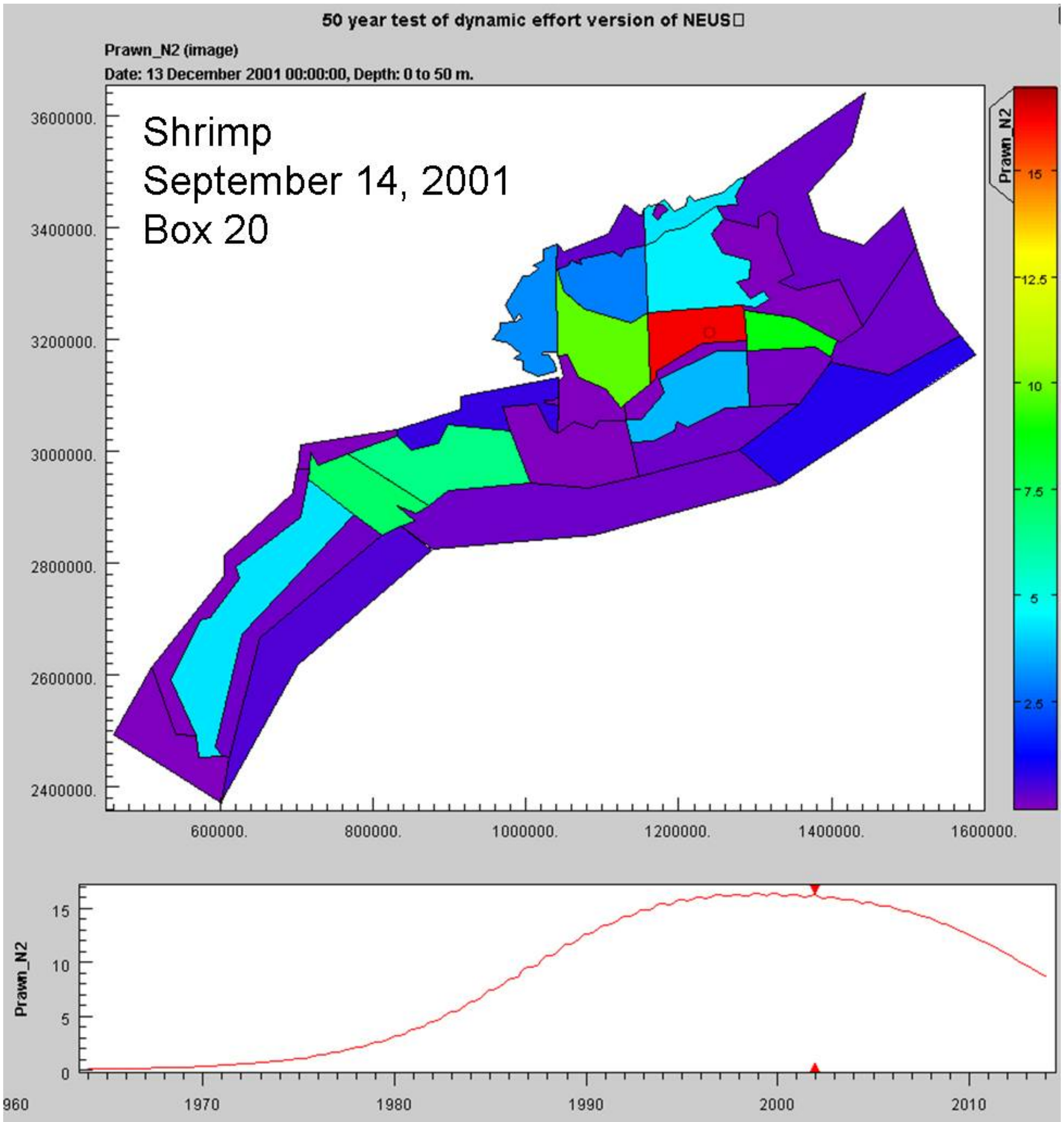


Figure 39. Shrimp spatial distribution on September 14, 2001 of the dynamic model run. The red dot indicates the currently selected box and the time series below shows the biomass in mt / km^2. Each box is indicated on the map, and the time series at the bottom shows abundance over the run of the model in the box indicated by the red dot on the map. The map itself shows the abundance at the specific time indicated in the upper left of the image (the time is also referenced with red triangles at the top and bottom of the time series). Cooler colors (blue, purple) on the map indicate lower abundance, while warmer colors (yellow, orange and red) indicate higher abundance.

Table A1. Vertebrate life history parameters. Parameters a and b are from the length-weight relationship ($W = aL^b$, as adapted from from Wigley et al. 2003). The remainder were informed from various stock assessments (http://www.nefsc.noaa.gov/sos/), fits to survey data (Azarovitz 1981, NEFC 1988) and expert opinion (J. Burnett, pers. comm.).

Code	Group	Age mature (years)	Max age (years)	Initial biomass (tons/m^3)	a	b	Bev-Holt alpha	Bev-Holt beta	Adult Mlin (linear mortality)	Juvenile Mlin (linear mortality)	Adult Mquad (quad mortality)	Juv Mquad (quad mortality)
FPL	Atlantic mackerel	2	10	6637.535	0.0126	3.3	3.55E+09	2.00E+12	0	0	2.50E-12	1.00E-14
FPS	Atlantic herring	2	10	4886.576	0.0115	2.9	7.55E+09	3.00E+11	0	0	1.00E-14	1.00E-14
FVD	White hake	3	10	32303.92	0.0126	3.2	1.70E+07	1.60E+10	3.80E-09	3.80E-09	3.75E-08	2.75E-09
FVS	Bluefish	1	10	2697.025	0.011	3	1.85E+08	1.00E+11	0	0	1.80E-09	9.25E-13
FVB	Other piscivores	6	20	94801.77	0.0124	3.2	5.80E+08	3.00E+10	0	0	3.20E-09	5.20E-10
FVT	Large piscivores	9	30	4837.667	0.0214	2.96	2.80E+07	6.00E+11	0	0	2.00E-08	5.00E-09
FMM	Migratory mesopelagics	2	10	20.87382	0.011	3.01	1.25E+06	1.00E+07	7.00E-07	7.00E-07	4.50E-09	4.00E-09
FBP	Benthopelagics	3	10	23718.14	0.0116	3	4.50E+08	3.00E+11	8.00E-12	8.00E-12	1.80E-10	2.25E-11
FDD	Goosefish	3	10	38974.77	0.0107	2.91	9.40E+07	1.00E+11	0	0	8.50E-09	2.50E-11
FDE	Shallow demersal fish	2	10	6329.917	0.0123	3.2	1.91E+09	2.00E+10	0	9.00E-13	8.00E-13	1.00E-14
FDS	Atlantic cod	4	20	93206.04	0.0118	3.1	3.70E+07	2.50E+10	0	8.25E-11	7.90E-09	1.50E-11
FDB	Silver hake	3	10	36660.84	0.0123	3.1	3.20E+08	6.00E+10	0	0	2.60E-09	1.50E-11
FDC	Miscellaneous demersals	2	20	261600.6	0.012	3.1	1.45E+09	1.00E+11	0	0	3.00E-10	3.00E-13
FDO	Haddock	2	20	126222.4	0.0118	3.1	2.18E+08	7.00E+11	0	0	4.00E-09	2.65E-11
FDF	Yellowtail flounder	2	10	30212.81	0.012	3.1	4.05E+08	2.50E+10	5.00E-19	5.00E-19	1.90E-09	1.00E-12
SHB	Spiny dogfish	12	40	306781.6	0.0129	3	5.80E+07	3.50E+12	0	0	1.00E-13	1.00E-14
SHD	Other demersal sharks	10	50	18788.62	0.00396	3.2	9.90E+05	2.00E+12	0	0	3.50E-10	5.00E-13
SHP	Pelagic sharks	14	70	7183.533	0.00524	3.141	2.00E+04	1.56E+10	0	0	4.50E-08	1.00E-08
SSK	Skates and rays	6	30	138910.8	0.0127	3.1	6.10E+07	2.00E+13	1.00E-10	1.00E-10	2.50E-09	5.00E-10
SB	Seabirds	2	20	1808.545	0.02	3	3.00E+06	1.05E+07	0	0	1.30E-06	4.30E-07
PIN	Pinnipeds	9	30	7660.843	0.035	2.9	4.00E+04	1.50E+09	9.00E-07	9.00E-07	6.90E-07	1.50E-07
REP	Reptiles	16	80	803.2799	0.00396	3.004	3.40E+04	1.50E+09	2.00E-07	2.00E-07	2.50E-07	5.50E-07
WHB	Baleen whales	27	90	90230.75	0.2	3	7.00E+00	3.00E+11	1.10E-08	1.10E-08	3.15E-05	1.50E-06
WHT	Toothed whales	21	70	19997.48	0.01	3	1.00E+03	5.00E+08	2.00E-08	2.00E-08	1.50E-05	4.50E-06

Table A2. Invertebrate life history parameters, as used in the final, calibrated versions of the model.

Code	Group	ML (Linear Mortality)	Mquad (Quadratic Mortality)
CEP	Squid	1.16E-11	1.70E-08
BFS	Sea scallop	3.47E-12	0.00E+00
BFF	Other benthic filter feeder	5.79E-12	0.00E+00
BG	Benthic grazer	1.16E-11	0.00E+00
BML	Lobster	2.31E-11	0.00E+00
BMS	Shallow macrozoobenthos	3.47E-11	0.00E+00
PWN	Shrimp	7.81E-11	2.05E-08
ZL	Carnivorous zooplankton	5.79E-11	1.16E-10
BD	Deposit feeder	1.16E-12	0.00E+00
BC	Benthic carnivore	9.26E-10	4.63E-11
ZG	Gelatinous zooplankton	3.47E-11	5.79E-11
PL	Diatoms	1.74E-08	0.00E+00
DF	Dinoflagellates	5.79E-09	0.00E+00
PS	Pico-phytoplankton	1.85E-07	0.00E+00
ZM	Copepods	1.16E-09	1.16E-11
ZS	Microzooplankton	9.26E-10	4.63E-10
PB	Pelagic bacteria	1.16E-09	0.00E+00
BB	Sediment bacteria	1.16E-10	0.00E+00
BO	Meiobenthos	4.63E-12	1.16E-12

Table A3. Initial biomass (g/m^2) per Atlantis NEUS region (See Figure 5) for each functional group. The boundary regions (0 and 23-29) have no initial biomass assigned to them.

CODE	GROUP	REGIONS										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
FBP	Benthopelagics	0.1171547	0.029229	0.02635	0.035685	0.012294	0.012681	0.030716	0.023108	0.018852	0.005167	4.73E-06
FDD	Goosefish	0.04978	0.08661	0.16588	0.15961	0.17914	0.27066	0.13708	0.16799	0.06422	0.045	0.13917
FDC	Miscellaneous demersals	1.00746	0.61552	1.02307	0.19687	1.07917	0.50473	0.52409	0.61559	0.29907	0.35346	0.79741
FDO	Haddock	0	0	0	0.00053	0.00333	0.00294	0.12768	1.19756	0.19681	1.4146	1.40334
FDF	Yellowtail flounder	0.00675	0.08468	0.03176	0.22144	0.48798	0.27651	0.25722	0.07985	0.0859	0.26283	0.15818
FDE	Shallow demersal fish	0.01	0.02099	0.01442	0.03162	0.04607	0.07694	0.06146	0.00529	0.00394	0.01426	0.02102
FDS	Atlantic cod	0.03299	0.03647	0.00065	0.13027	0.19032	0.09644	0.15213	1.29409	0.09224	0.66682	0.63332
FDB	Silver hake	0.02699	0.07124	0.09998	0.15429	0.11174	0.31658	0.14032	0.04203	0.12529	0.02031	0.26348
FMM	Migratory mesopelagics	0	0	0.00039	0.00106	0	0.00008	0	0	0	0	0.00047
FPL	Atlantic mackerel	0.01716	0.02998	0.0468	0.12642	0.03099	0.11895	0.01276	0.00167	0.01583	0.00534	0.00203
FPS	Atlantic herring	0.01461	0.01214	0.0018	0.02026	0.0178	0.05968	0.01127	0.03248	0.01331	0.00458	0.03655
FVD	White hake	0.00034	0.00058	0.00412	0.00704	0.01259	0.01898	0.0234	0.05139	0.02574	0.00393	0.0924
FVS	Bluefish	0.05955	0.01301	0.01212	0.01688	0.02009	0.01547	0.01331	0.00204	0	0.02153	0.01175
FVB	Other piscivores	0.21618	0.15846	0.08666	0.32813	0.72087	0.45959	0.5505	0.54613	0.33716	0.54811	0.39904
FVT	Large piscivores	0.0061327	0.006133	0.006133	0.006133	0.006133	0.006133	0.006133	0.040486	0.040486	0.040486	0.040486
PIN	Pinnipeds	0.0001453	0.000145	0.000145	0.000145	0.01382	0.01382	0.01382	0	0	0	0
SB	Seabirds	0.0036315	0.003631	0.003631	0.003631	0.006303	0.006303	0.006303	0.014212	0.014212	0.014212	0.014212
SHD	Other demersal sharks	0.52146	0.21479	0.02589	0.0771	0.10913	0.03937	0.0091	0.28002	0	0.0011	0.00087
SHB	Spiny dogfish	0.2845	0.8562	3.1788	2.8987	1.9556	3.154	1.5015	1.84529	0.5321	0.7209	0.5663
SHP	Pelagic sharks	0.026886	0.026886	0.026886	0.026886	0.026886	0.026886	0.026886	0.039443	0.039443	0.039443	0.039443
SSK	Skates and rays	0.58863	0.5704	0.09202	0.24382	1.34725	0.46329	0.66319	1.42784	0.21112	1.27358	1.01859
REP	Reptiles	0.0093287	0.009329	0.009329	0.009329	0.002498	0.002498	0.002498	0.000319	0.000319	0.000319	0.000319
WHB	Baleen whales	0.0661091	0.066109	0.066109	0.066109	0.210102	0.210102	0.210102	0.234384	0.234384	0.234384	0.234384
WHT	Toothed whales	0.0409291	0.040929	0.040929	0.040929	0.0759	0.0759	0.0759	0.159909	0.159909	0.159909	0.159909
CEP	Squid	0.07413	0.23718	0.40625	0.21005	0.20565	0.22411	0.19327	0.11829	0.09139	0.09211	0.14516
PWN	Shrimp	0.0002	0.0003	0.0006	0.0007	0.0003	0.0003	0.0006	0.0025	0.0008	0.0003	0.0082
BML	Lobster	0.00222	0.00335	0.05851	0.02132	0.03433	0.03874	0.05405	0.03371	0.06286	0.04376	0.02382
ZL	Carnivorous zooplankton	0.2856923	0.285692	0.285692	0.285692	6.335461	6.335461	6.335461	3.713601	3.713601	3.713601	3.713601

Table A3, continued. Initial biomass (g/m²) per Atlantis NEUS region (See Figure 5) for each functional group. The boundary regions (0 and 23-29) have no initial biomass assigned to them.

CODE	GROUP	REGIONS										
		12	13	14	15	16	17	18	19	20	21	22
FBP	Benthopelagics	0.001074	0.003007	0.002229	0.001622	5.12E-05	9.64E-06	0.000112	0	8.00E-06	7.06E-06	0.000129
FDD	Goosefish	0.25625	0.1656	0.17226	0.22522	0.22385	0.13471	0.07443	0.05979	0.28732	0.15013	0.10137
FDC	Miscellaneous demersals	1.30699	0.95555	0.53489	0.40182	2.32087	2.50604	0.8964	0.62997	2.04359	1.77373	0.17888
FDO	Haddock	0.6739	1.10575	0.29424	0.23266	0.16983	0.31493	1.78728	1.27686	0.85411	0.72262	0
FDF	Yellowtail flounder	0.06872	0.00382	0.00729	0.00939	0.00038	0.00031	0.02635	0.23119	0.00156	0.00058	0.08429
FDE	Shallow demersal fish	0.02198	0.0017	0.10802	0.06479	0.00675	0.00497	0.00617	0.00692	0.00475	0.00561	0.00857
FDS	Atlantic cod	1.02943	0.76876	0.70157	0.48356	0.50887	0.21427	0.63433	0.62475	0.56611	0.45438	0.06351
FDB	Silver hake	0.23859	0.11488	0.22793	0.12311	0.19232	0.1247	0.02952	0.05299	0.29248	0.26333	0.0697
FMM	Migratory mesopelagics	0.00001	0	0	0	0	0	0	0	0	0	0
FPL	Atlantic mackerel	0.01108	0.00004	0.01248	0.00024	0.00141	0.00095	0.00053	0.00926	0.0002	0.00016	0.00008
FPS	Atlantic herring	0.11635	0.00247	0.00154	0.00372	0.00429	0.00303	0.01037	0.01555	0.00784	0.0018	0.01035
FVD	White hake	0.2321	0.10892	0.43244	0.20891	0.48373	0.49921	0.05655	0.01534	0.32881	0.29882	0.00025
FVS	Bluefish	0	0	0.00043	0.00015	0	0	0	0.00274	0	0	0.02168
FVB	Other piscivores	0.58589	0.02958	0.56918	0.56914	0.38442	0.2822	0.23891	0.40809	0.33399	0.22798	0.5818
FVT	Large piscivores	0.022342	0.022342	0.022342	0.022342	0.022342	0.022342	0.022342	0.040486	0.022342	0.022342	0.006133
PIN	Pinnipeds	0.070454	0.070454	0.070454	0.070454	0.070454	0.070454	0.070454	0	0.070454	0.070454	0.000145
SB	Seabirds	0.005828	0.005828	0.005828	0.005828	0.005828	0.005828	0.005828	0.014212	0.005828	0.005828	0.006303
SHD	Other demersal sharks	0	0	0	0	0.00051	0	0	0	0	0	0.21981
SHB	Spiny dogfish	1.1283	0.7989	0.6749	0.52803	0.24271	0.4522	0.56666	0.25401	0.35448	1.03494	0
SHP	Pelagic sharks	0.021766	0.021766	0.021766	0.021766	0.021766	0.021766	0.021766	0.039443	0.021766	0.021766	0.026886
SSK	Skates and rays	0.25762	0.27265	0.22389	0.16455	0.5102	0.28063	0.21384	0.76513	0.49757	0.40081	0.5298
REP	Reptiles	8.32E-05	8.32E-05	8.32E-05	8.32E-05	8.32E-05	8.32E-05	8.32E-05	0.000319	8.32E-05	8.32E-05	0.009329
WHB	Baleen whales	0.650984	0.650984	0.650984	0.650984	0.650984	0.650984	0.650984	0.234384	0.650984	0.650984	0.066109
WHT	Toothed whales	0.06074	0.06074	0.06074	0.06074	0.06074	0.06074	0.06074	0.159909	0.06074	0.06074	0.040929
CEP	Squid	0.06857	0.02536	0.1371	0.76683	0.01907	0.01344	0.01263	0.06397	0.0348	0.01468	0.0549
PWN	Shrimp	0.1345	0.0038	0.0323	0.051	0.3424	0.0191	0.0038	0.0005	0.0476	0.0152	0
BML	Lobster	0.02205	0.04164	0.02929	0.03667	0.00775	0.00887	0.01491	0.03697	0.00968	0.02577	0.01814
ZL	Carnivorous zooplankton	0.185756	0.185756	0.185756	0.185756	0.185756	0.185756	0.185756	3.713601	0.185756	0.185756	6.335461

Table A4. Distribution of adult stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from January to March.

CODE	GROUP	REGIONS										
		1	2	3	4	5	6	7	8	9	10	11
FBP	Benthopelagics	0.139	0.071	0.226	0.087	0.069	0.093	0.107	0.08	0.021	0.01	0.008
FDD	Goosefish	0.014	0.026	0.05	0.048	0.054	0.082	0.041	0.051	0.019	0.014	0.042
FDC	Miscellaneous demersals	0.047	0.03	0.05	0.01	0.052	0.025	0.025	0.03	0.015	0.017	0.039
FDO	Haddock	0	0	0	0	0	0	0.011	0.102	0.017	0.12	0.119
FDF	Yellowtail flounder	0.004	0.035	0.013	0.093	0.204	0.116	0.108	0.033	0.036	0.11	0.066
FDE	Shallow demersal fish	0.019	0.038	0.026	0.058	0.084	0.141	0.113	0.01	0.007	0.026	0.038
FDS	Atlantic cod	0.003	0.004	0	0.014	0.02	0.01	0.016	0.138	0.01	0.071	0.068
FDB	Silver hake	0.009	0.023	0.032	0.05	0.036	0.102	0.045	0.014	0.04	0.007	0.085
FMM	Migratory mesopelagics	0	0	0.188	0	0.107	0.12	0	0	0.2	0	0.1
FPL	Atlantic mackerel	0.1	0.1	0.105	0.284	0.1	0.23	0.03	0.01	0.03	0.001	0
FPS	Atlantic herring	0.1	0.1	0.105	0.284	0.1	0.23	0.03	0.01	0.03	0.001	0
FVD	White hake	0	0	0.003	0.002	0.004	0.007	0.008	0.018	0.009	0.001	0.032
FVS	Bluefish	0.23	0.178	0.097	0.119	0.104	0.08	0.069	0.011	0	0.112	0
FVB	Other piscivores	0.026	0.019	0.01	0.038	0.084	0.054	0.064	0.064	0.039	0.064	0.047
FVT	Large piscivores	0	0	0.101	0.003	0.105	0.2	0.01	0.05	0.2	0.001	0
PIN	Pinnipeds	0	0	0	0	0	0	0.061	0.05	0.01	0.3	0.02
SB	Seabirds	0.022	0.022	0.022	0.022	0.039	0.039	0.039	0.087	0.087	0.087	0.087
SHD	Other demersal sharks	0.348	0.143	0.017	0.051	0.073	0.026	0.006	0.187	0	0.001	0.001
SHB	Spiny dogfish	0.1	0.1	0.105	0.284	0.1	0.23	0.03	0.01	0.03	0.001	0
SHP	Pelagic sharks	0.1	0.1	0.105	0.284	0.1	0.23	0.03	0.01	0.03	0.001	0
SSK	Skates and rays	0.049	0.047	0.008	0.02	0.112	0.039	0.055	0.119	0.018	0.106	0.085
REP	Reptiles	0.299	0.162	0.088	0.108	0.095	0.073	0.063	0.01	0	0.102	0
WHB	Baleen whales	0.008	0.008	0.008	0.008	0.008	0.026	0.026	0.029	0.026	0.081	0.081
WHT	Toothed whales	0.023	0.023	0.023	0.023	0.043	0.043	0.043	0.09	0.09	0.09	0.09
CEP	Squid	0.083	0.083	0.083	0.083	0.083	0.095	0.083	0.083	0.11	0.03	0.03
PWN	Shrimp	0	0	0.001	0	0.001	0	0	0.004	0.001	0.202	0.072
BML	Lobster	0.004	0.005	0.093	0.029	0.034	0.062	0.055	0.054	0.086	0.035	0.015
ZL	Carnivorous zooplankton	0.018	0.009	0.002	0.337	0.003	0.063	0.205	0.078	0.081	0.003	0.001

Table A4, continued. Distribution of adult stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from January to March.

CODE	GROUP	REGIONS										
		12	13	14	15	16	17	18	19	20	21	22
FBP	Benthopelagics	0.026	0	0	0.001	0.001	0	0.001	0.011	0	0	0.049
FDD	Goosefish	0.077	0.05	0.052	0.068	0.068	0.041	0.022	0.018	0.087	0.045	0.031
FDC	Miscellaneous demersals	0.064	0.046	0.026	0.02	0.113	0.122	0.044	0.031	0.099	0.086	0.009
FDO	Haddock	0.057	0.094	0.025	0.02	0.014	0.027	0.152	0.108	0.073	0.061	0
FDF	Yellowtail flounder	0.029	0.002	0.003	0.004	0	0	0.011	0.097	0.001	0	0.035
FDE	Shallow demersal fish	0.04	0.003	0.198	0.119	0.012	0.009	0.011	0.013	0.009	0.01	0.016
FDS	Atlantic cod	0.11	0.082	0.075	0.052	0.054	0.023	0.068	0.067	0.06	0.048	0.007
FDB	Silver hake	0.077	0.037	0.073	0.04	0.062	0.04	0.01	0.017	0.094	0.085	0.022
FMM	Migratory mesopelagics	0.035	0	0.2	0	0	0	0	0	0.05	0	0
FPL	Atlantic mackerel	0	0	0.01	0	0	0	0	0	0	0	0
FPS	Atlantic herring	0	0	0.01	0	0	0	0	0	0	0	0
FVD	White hake	0.08	0.037	0.149	0.072	0.166	0.172	0.019	0.005	0.113	0.103	0
FVS	Bluefish	0	0	0	0	0	0	0	0	0	0	0
FVB	Other piscivores	0.068	0.003	0.066	0.066	0.045	0.033	0.028	0.048	0.039	0.027	0.068
FVT	Large piscivores	0	0	0.17	0.16	0	0	0	0	0	0	0
PIN	Pinnipeds	0.104	0.001	0	0	0.15	0.15	0.154	0	0	0	0
SB	Seabirds	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.087	0.036	0.036	0.039
SHD	Other demersal sharks	0	0	0	0	0	0	0	0	0	0	0.147
SHB	Spiny dogfish	0	0	0.01	0	0	0	0	0	0	0	0
SHP	Pelagic sharks	0	0	0.01	0	0	0	0	0	0	0	0
SSK	Skates and rays	0.021	0.023	0.019	0.014	0.042	0.023	0.018	0.064	0.041	0.033	0.044
REP	Reptiles	0	0	0	0	0	0	0	0	0	0	0
WHB	Baleen whales	0.029	0.029	0.029	0.029	0.081	0.081	0.081	0.081	0.081	0.081	0.081
WHT	Toothed whales	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.09	0.034	0.034	0.023
CEP	Squid	0.03	0.03	0.03	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
PWN	Shrimp	0.012	0	0.001	0.001	0.515	0.049	0.077	0.029	0.023	0.006	0.006
BML	Lobster	0.038	0.07	0.1	0.059	0.012	0.047	0.058	0.014	0.041	0.066	0.024
ZL	Carnivorous zooplankton	0.037	0.083	0.029	0.04	0.001	0.002	0.002	0.001	0.001	0.001	0.002

Table A5. Distribution of adult stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from April to June.

CODE	GROUP	REGIONS										
		1	2	3	4	5	6	7	8	9	10	11
FBP	Benthopelagics	0.139	0.071	0.226	0.087	0.069	0.093	0.107	0.08	0.021	0.01	0.008
FDD	Goosefish	0.014	0.026	0.05	0.048	0.054	0.082	0.041	0.051	0.019	0.014	0.042
FDC	Miscellaneous demersals	0.047	0.03	0.05	0.01	0.052	0.025	0.025	0.03	0.015	0.017	0.039
FDO	Haddock	0	0	0	0	0	0	0.011	0.102	0.017	0.12	0.119
FDF	Yellowtail flounder	0.004	0.035	0.013	0.093	0.204	0.116	0.108	0.033	0.036	0.11	0.066
FDE	Shallow demersal fish	0.019	0.038	0.026	0.058	0.084	0.141	0.113	0.01	0.007	0.026	0.038
FDS	Atlantic cod	0.003	0.004	0	0.014	0.02	0.01	0.016	0.138	0.01	0.071	0.068
FDB	Silver hake	0.009	0.023	0.032	0.05	0.036	0.102	0.045	0.014	0.04	0.007	0.085
FMM	Migratory mesopelagics	0	0	0.188	0	0.107	0.12	0	0	0.2	0	0.1
FPL	Atlantic mackerel	0.001	0.001	0.001	0.234	0.1	0.268	0.1	0.07	0.1	0.02	0.005
FPS	Atlantic herring	0.001	0.001	0.001	0.234	0.1	0.268	0.1	0.07	0.1	0.02	0.005
FVD	White hake	0	0	0.003	0.002	0.004	0.007	0.008	0.018	0.009	0.001	0.032
FVS	Bluefish	0.202	0.042	0.038	0.14	0.095	0.073	0.123	0.01	0	0.102	0.056
FVB	Other piscivores	0.026	0.019	0.01	0.038	0.084	0.054	0.064	0.084	0.039	0.064	0.047
FVT	Large piscivores	0	0	0.101	0.003	0.105	0.1	0.01	0.05	0.25	0.001	0
PIN	Pinnipeds	0	0	0	0	0	0	0.061	0.05	0.01	0.3	0.02
SB	Seabirds	0.022	0.022	0.022	0.022	0.039	0.039	0.039	0.087	0.087	0.087	0.087
SHD	Other demersal sharks	0.348	0.143	0.017	0.051	0.073	0.026	0.006	0.187	0	0.001	0.001
SHB	Spiny dogfish	0.001	0.001	0.001	0.234	0.1	0.268	0.1	0.07	0.1	0.02	0.005
SHP	Pelagic sharks	0.001	0.001	0.001	0.234	0.1	0.268	0.1	0.07	0.1	0.02	0.005
SSK	Skates and rays	0.049	0.047	0.008	0.02	0.112	0.039	0.055	0.119	0.018	0.106	0.085
REP	Reptiles	0.202	0.042	0.038	0.14	0.095	0.073	0.123	0.01	0	0.102	0.056
WHB	Baleen whales	0.008	0.008	0.008	0.008	0.008	0.026	0.026	0.029	0.026	0.081	0.081
WHT	Toothed whales	0.023	0.023	0.023	0.023	0.043	0.043	0.043	0.09	0.09	0.09	0.09
CEP	Squid	0.071	0.072	0.072	0.072	0.072	0.083	0.072	0.072	0.1	0.05	0.05
PWN	Shrimp	0	0	0.001	0	0.001	0	0	0.004	0.001	0.202	0.072
BML	Lobster	0.004	0.005	0.093	0.029	0.034	0.062	0.055	0.054	0.086	0.035	0.015
ZL	Carnivorous zooplankton	0.018	0.009	0.002	0.337	0.003	0.063	0.205	0.078	0.081	0.003	0.001

Table A5, continued. Distribution of adult stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from April to June.

CODE	GROUP	REGIONS										
		12	13	14	15	16	17	18	19	20	21	22
FBP	Benthopelagics	0.026	0	0	0.001	0.001	0	0.001	0.011	0	0	0.049
FDD	Goosefish	0.077	0.05	0.052	0.068	0.068	0.041	0.022	0.018	0.087	0.045	0.031
FDC	Miscellaneous demersals	0.064	0.046	0.026	0.02	0.113	0.122	0.044	0.031	0.099	0.086	0.009
FDO	Haddock	0.057	0.094	0.025	0.02	0.014	0.027	0.152	0.108	0.073	0.061	0
FDF	Yellowtail flounder	0.029	0.002	0.003	0.004	0	0	0.011	0.097	0.001	0	0.035
FDE	Shallow demersal fish	0.04	0.003	0.198	0.119	0.012	0.009	0.011	0.013	0.009	0.01	0.016
FDS	Atlantic cod	0.11	0.082	0.075	0.052	0.054	0.023	0.068	0.067	0.06	0.048	0.007
FDB	Silver hake	0.077	0.037	0.073	0.04	0.062	0.04	0.01	0.017	0.094	0.085	0.022
FMM	Migratory mesopelagics	0.035	0	0.2	0	0	0	0	0	0.05	0	0
FPL	Atlantic mackerel	0.025	0	0.07	0.001	0.003	0	0.001	0	0	0	0
FPS	Atlantic herring	0.025	0	0.07	0.001	0.003	0	0.001	0	0	0	0
FVD	White hake	0.08	0.037	0.149	0.072	0.166	0.172	0.019	0.005	0.113	0.103	0
FVS	Bluefish	0	0	0.002	0.001	0	0	0	0.013	0	0	0.103
FVB	Other piscivores	0.068	0.003	0.066	0.066	0.045	0.033	0.028	0.038	0.039	0.017	0.068
FVT	Large piscivores	0	0	0.22	0.16	0	0	0	0	0	0	0
PIN	Pinnipeds	0.104	0.001	0	0	0.15	0.15	0.154	0	0	0	0
SB	Seabirds	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.087	0.036	0.036	0.039
SHD	Other demersal sharks	0	0	0	0	0	0	0	0	0	0	0.147
SHB	Spiny dogfish	0.025	0	0.07	0.001	0.003	0	0.001	0	0	0	0
SHP	Pelagic sharks	0.025	0	0.07	0.001	0.003	0	0.001	0	0	0	0
SSK	Skates and rays	0.021	0.023	0.019	0.014	0.042	0.023	0.018	0.064	0.041	0.033	0.044
REP	Reptiles	0	0	0.002	0.001	0	0	0	0.013	0	0	0.103
WHB	Baleen whales	0.029	0.029	0.029	0.029	0.081	0.081	0.081	0.081	0.081	0.081	0.081
WHT	Toothed whales	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.09	0.034	0.034	0.023
CEP	Squid	0.05	0.05	0.05	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
PWN	Shrimp	0.012	0	0.001	0.001	0.515	0.049	0.077	0.029	0.023	0.006	0.006
BML	Lobster	0.038	0.07	0.1	0.059	0.012	0.047	0.058	0.014	0.041	0.066	0.024
ZL	Carnivorous zooplankton	0.037	0.083	0.029	0.04	0.001	0.002	0.002	0.001	0.001	0.001	0.002

Table A6. Distribution of adult stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from July to September.

CODE	GROUP	REGIONS										
		1	2	3	4	5	6	7	8	9	10	11
FBP	Benthopelagics	0.139	0.071	0.226	0.087	0.069	0.093	0.107	0.08	0.021	0.01	0.008
FDD	Goosefish	0.014	0.026	0.05	0.048	0.054	0.082	0.041	0.051	0.019	0.014	0.042
FDC	Miscellaneous demersals	0.047	0.03	0.05	0.01	0.052	0.025	0.025	0.03	0.015	0.017	0.039
FDO	Haddock	0	0	0	0	0	0	0.011	0.102	0.017	0.12	0.119
FDF	Yellowtail flounder	0.004	0.035	0.013	0.093	0.204	0.116	0.108	0.033	0.036	0.11	0.066
FDE	Shallow demersal fish	0.019	0.038	0.026	0.058	0.084	0.141	0.113	0.01	0.007	0.026	0.038
FDS	Atlantic cod	0.003	0.004	0	0.014	0.02	0.01	0.016	0.138	0.01	0.071	0.068
FDB	Silver hake	0.009	0.023	0.032	0.05	0.036	0.102	0.045	0.014	0.04	0.007	0.085
FMM	Migratory mesopelagics	0	0	0.188	0	0.107	0.12	0	0	0.2	0	0.1
FPL	Atlantic mackerel	0	0	0	0	0	0	0	0.001	0.001	0.08	0.03
FPS	Atlantic herring	0	0	0	0	0	0	0	0.001	0.001	0.08	0.03
FVD	White hake	0	0	0.003	0.002	0.004	0.007	0.008	0.018	0.009	0.001	0.032
FVS	Bluefish	0.202	0.042	0.038	0.14	0.095	0.073	0.123	0.01	0	0.102	0.056
FVB	Other piscivores	0.026	0.019	0.01	0.038	0.084	0.054	0.064	0.064	0.039	0.064	0.047
FVT	Large piscivores	0	0	0.101	0.003	0.105	0.1	0.01	0.05	0.25	0.001	0
PIN	Pinnipeds	0	0	0	0	0	0	0.061	0.05	0.01	0.3	0.02
SB	Seabirds	0.022	0.022	0.022	0.022	0.039	0.039	0.039	0.087	0.087	0.087	0.087
SHD	Other demersal sharks	0.348	0.143	0.017	0.051	0.073	0.026	0.006	0.187	0	0.001	0.001
SHB	Spiny dogfish	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.001	0.07	0.08	0.03
SHP	Pelagic sharks	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.001	0.07	0.08	0.03
SSK	Skates and rays	0.049	0.047	0.008	0.02	0.112	0.039	0.055	0.119	0.018	0.106	0.085
REP	Reptiles	0.202	0.042	0.038	0.14	0.095	0.073	0.123	0.01	0	0.102	0.056
WHB	Baleen whales	0.008	0.008	0.008	0.008	0.008	0.026	0.026	0.029	0.026	0.081	0.081
WHT	Toothed whales	0.023	0.023	0.023	0.023	0.043	0.043	0.043	0.09	0.09	0.09	0.09
CEP	Squid	0.071	0.072	0.072	0.072	0.072	0.083	0.072	0.072	0.1	0.05	0.05
PWN	Shrimp	0	0	0.001	0	0.001	0	0	0.004	0.001	0.202	0.072
BML	Lobster	0.004	0.005	0.093	0.029	0.034	0.062	0.055	0.054	0.086	0.035	0.015
ZL	Carnivorous zooplankton	0.018	0.009	0.002	0.337	0.003	0.063	0.205	0.078	0.081	0.003	0.001

Table A6, continued. Distribution of adult stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from July to September.

CODE	GROUP	REGIONS										
		12	13	14	15	16	17	18	19	20	21	22
FBP	Benthopelagics	0.026	0	0	0.001	0.001	0	0.001	0.011	0	0	0.049
FDD	Goosefish	0.077	0.05	0.052	0.068	0.068	0.041	0.022	0.018	0.087	0.045	0.031
FDC	Miscellaneous demersals	0.064	0.046	0.026	0.02	0.113	0.122	0.044	0.031	0.099	0.086	0.009
FDO	Haddock	0.057	0.094	0.025	0.02	0.014	0.027	0.152	0.108	0.073	0.061	0
FDF	Yellowtail flounder	0.029	0.002	0.003	0.004	0	0	0.011	0.097	0.001	0	0.035
FDE	Shallow demersal fish	0.04	0.003	0.198	0.119	0.012	0.009	0.011	0.013	0.009	0.01	0.016
FDS	Atlantic cod	0.11	0.082	0.075	0.052	0.054	0.023	0.068	0.067	0.06	0.048	0.007
FDB	Silver hake	0.077	0.037	0.073	0.04	0.062	0.04	0.01	0.017	0.094	0.085	0.022
FMM	Migratory mesopelagics	0.035	0	0.2	0	0	0	0	0	0.05	0	0
FPL	Atlantic mackerel	0.09	0.08	0.06	0.227	0.02	0.05	0.05	0.021	0.05	0.13	0.11
FPS	Atlantic herring	0.09	0.08	0.06	0.227	0.02	0.05	0.05	0.021	0.05	0.13	0.11
FVD	White hake	0.08	0.037	0.149	0.072	0.166	0.172	0.019	0.005	0.113	0.103	0
FVS	Bluefish	0	0	0.002	0.001	0	0	0	0.013	0	0	0.103
FVB	Other piscivores	0.068	0.003	0.066	0.066	0.045	0.033	0.028	0.048	0.039	0.027	0.068
FVT	Large piscivores	0	0	0.22	0.16	0	0	0	0	0	0	0
PIN	Pinnipeds	0.104	0.001	0	0	0.15	0.15	0.154	0	0	0	0
SB	Seabirds	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.087	0.036	0.036	0.039
SHD	Other demersal sharks	0	0	0	0	0	0	0	0	0	0	0.147
SHB	Spiny dogfish	0.09	0.08	0.08	0.12	0.02	0.05	0.05	0.021	0.04	0.1	0.1
SHP	Pelagic sharks	0.09	0.08	0.08	0.12	0.02	0.05	0.05	0.021	0.04	0.1	0.1
SSK	Skates and rays	0.021	0.023	0.019	0.014	0.042	0.023	0.018	0.064	0.041	0.033	0.044
REP	Reptiles	0	0	0.002	0.001	0	0	0	0.013	0	0	0.103
WHB	Baleen whales	0.029	0.029	0.029	0.029	0.081	0.081	0.081	0.081	0.081	0.081	0.081
WHT	Toothed whales	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.09	0.034	0.034	0.023
CEP	Squid	0.05	0.05	0.05	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
PWN	Shrimp	0.012	0	0.001	0.001	0.515	0.049	0.077	0.029	0.023	0.006	0.006
BML	Lobster	0.038	0.07	0.1	0.059	0.012	0.047	0.058	0.014	0.041	0.066	0.024
ZL	Carnivorous zooplankton	0.037	0.083	0.029	0.04	0.001	0.002	0.002	0.001	0.001	0.001	0.002

Table A7. Distribution of adult stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from October to December.

CODE	GROUP	REGIONS										
		1	2	3	4	5	6	7	8	9	10	11
FBP	Benthopelagics	0.139	0.071	0.226	0.087	0.069	0.093	0.107	0.08	0.021	0.01	0.008
FDD	Goosefish	0.014	0.026	0.05	0.048	0.054	0.082	0.041	0.051	0.019	0.014	0.042
FDC	Miscellaneous demersals	0.047	0.03	0.05	0.01	0.052	0.025	0.025	0.03	0.015	0.017	0.039
FDO	Haddock	0	0	0	0	0	0	0.011	0.102	0.017	0.12	0.119
FDF	Yellowtail flounder	0.004	0.035	0.013	0.093	0.204	0.116	0.108	0.033	0.036	0.11	0.066
FDE	Shallow demersal fish	0.019	0.038	0.026	0.058	0.084	0.141	0.113	0.01	0.007	0.026	0.038
FDS	Atlantic cod	0.003	0.004	0	0.014	0.02	0.01	0.016	0.138	0.01	0.071	0.068
FDB	Silver hake	0.009	0.023	0.032	0.05	0.036	0.102	0.045	0.014	0.04	0.007	0.085
FMM	Migratory mesopelagics	0	0	0.188	0	0.107	0.12	0	0	0.2	0	0.1
FPL	Atlantic mackerel	0.039	0.067	0.105	0.284	0.07	0.268	0.029	0.004	0.036	0.012	0.005
FPS	Atlantic herring	0.036	0.03	0.004	0.05	0.044	0.149	0.028	0.081	0.033	0.011	0.091
FVD	White hake	0	0	0.003	0.002	0.004	0.007	0.008	0.018	0.009	0.001	0.032
FVS	Bluefish	0.23	0.178	0.097	0.119	0.104	0.08	0.069	0.011	0	0.112	0
FVB	Other piscivores	0.026	0.019	0.01	0.038	0.084	0.054	0.064	0.064	0.039	0.064	0.047
FVT	Large piscivores	0	0	0.101	0.003	0.105	0.2	0.01	0.05	0.2	0.001	0
PIN	Pinnipeds	0	0	0	0	0	0	0.061	0.05	0.01	0.3	0.02
SB	Seabirds	0.022	0.022	0.022	0.022	0.039	0.039	0.039	0.087	0.087	0.087	0.087
SHD	Other demersal sharks	0.348	0.143	0.017	0.051	0.073	0.026	0.006	0.187	0	0.001	0.001
SHB	Spiny dogfish	0.039	0.067	0.105	0.284	0.07	0.268	0.029	0.004	0.036	0.012	0.005
SHP	Pelagic sharks	0.039	0.067	0.105	0.284	0.07	0.268	0.029	0.004	0.036	0.012	0.005
SSK	Skates and rays	0.049	0.047	0.008	0.02	0.112	0.039	0.055	0.119	0.018	0.106	0.085
REP	Reptiles	0.299	0.162	0.088	0.108	0.095	0.073	0.063	0.01	0	0.102	0
WHB	Baleen whales	0.008	0.008	0.008	0.008	0.008	0.026	0.026	0.029	0.026	0.081	0.081
WHT	Toothed whales	0.023	0.023	0.023	0.023	0.043	0.043	0.043	0.09	0.09	0.09	0.09
CEP	Squid	0.083	0.083	0.083	0.083	0.083	0.095	0.083	0.083	0.11	0.03	0.03
PWN	Shrimp	0	0	0.001	0	0.001	0	0	0.004	0.001	0.202	0.072
BML	Lobster	0.004	0.005	0.093	0.029	0.034	0.062	0.055	0.054	0.086	0.035	0.015
ZL	Carnivorous zooplankton	0.018	0.009	0.002	0.337	0.003	0.063	0.205	0.078	0.081	0.003	0.001

Table A7, continued. Distribution of adult stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from October to December.

CODE	GROUP	REGIONS										
		12	13	14	15	16	17	18	19	20	21	22
FBP	Benthopelagics	0.026	0	0	0.001	0.001	0	0.001	0.011	0	0	0.049
FDD	Goosefish	0.077	0.05	0.052	0.068	0.068	0.041	0.022	0.018	0.087	0.045	0.031
FDC	Miscellaneous demersals	0.064	0.046	0.026	0.02	0.113	0.122	0.044	0.031	0.099	0.086	0.009
FDO	Haddock	0.057	0.094	0.025	0.02	0.014	0.027	0.152	0.108	0.073	0.061	0
FDF	Yellowtail flounder	0.029	0.002	0.003	0.004	0	0	0.011	0.097	0.001	0	0.035
FDE	Shallow demersal fish	0.04	0.003	0.198	0.119	0.012	0.009	0.011	0.013	0.009	0.01	0.016
FDS	Atlantic cod	0.11	0.082	0.075	0.052	0.054	0.023	0.068	0.067	0.06	0.048	0.007
FDB	Silver hake	0.077	0.037	0.073	0.04	0.062	0.04	0.01	0.017	0.094	0.085	0.022
FMM	Migratory mesopelagics	0.035	0	0.2	0	0	0	0	0	0.05	0	0
FPL	Atlantic mackerel	0.025	0	0.028	0.001	0.003	0.002	0.001	0.021	0	0	0
FPS	Atlantic herring	0.29	0.006	0.004	0.009	0.011	0.008	0.026	0.039	0.02	0.004	0.026
FVD	White hake	0.08	0.037	0.149	0.072	0.166	0.172	0.019	0.005	0.113	0.103	0
FVS	Bluefish	0	0	0	0	0	0	0	0	0	0	0
FVB	Other piscivores	0.068	0.003	0.066	0.066	0.045	0.033	0.028	0.048	0.039	0.027	0.068
FVT	Large piscivores	0	0	0.17	0.16	0	0	0	0	0	0	0
PIN	Pinnipeds	0.104	0.001	0	0	0.15	0.15	0.154	0	0	0	0
SB	Seabirds	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.087	0.036	0.036	0.039
SHD	Other demersal sharks	0	0	0	0	0	0	0	0	0	0	0.147
SHB	Spiny dogfish	0.025	0	0.028	0.001	0.003	0.002	0.001	0.021	0	0	0
SHP	Pelagic sharks	0.025	0	0.028	0.001	0.003	0.002	0.001	0.021	0	0	0
SSK	Skates and rays	0.021	0.023	0.019	0.014	0.042	0.023	0.018	0.064	0.041	0.033	0.044
REP	Reptiles	0	0	0	0	0	0	0	0	0	0	0
WHB	Baleen whales	0.029	0.029	0.029	0.029	0.081	0.081	0.081	0.081	0.081	0.081	0.081
WHT	Toothed whales	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.09	0.034	0.034	0.023
CEP	Squid	0.03	0.03	0.03	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
PWN	Shrimp	0.012	0	0.001	0.001	0.515	0.049	0.077	0.029	0.023	0.006	0.006
BML	Lobster	0.038	0.07	0.1	0.059	0.012	0.047	0.058	0.014	0.041	0.066	0.024
ZL	Carnivorous zooplankton	0.037	0.083	0.029	0.04	0.001	0.002	0.002	0.001	0.001	0.001	0.002

Table A8. Distribution of juvenile stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from January to March.

CODE	GROUP	REGIONS										
		1	2	3	4	5	6	7	8	9	10	11
FBP	Benthopelagics	0.139	0.071	0.226	0.087	0.069	0.093	0.107	0.08	0.021	0.01	0.008
FDD	Goosefish	0.014	0.026	0.05	0.048	0.054	0.082	0.041	0.051	0.019	0.014	0.042
FDC	Miscellaneous demersals	0.047	0.03	0.05	0.01	0.052	0.025	0.025	0.03	0.015	0.017	0.039
FDO	Haddock	0	0	0	0	0	0	0.011	0.102	0.017	0.12	0.119
FDF	Yellowtail flounder	0.004	0.035	0.013	0.093	0.204	0.116	0.108	0.033	0.036	0.11	0.066
FDE	Shallow demersal fish	0.019	0.038	0.026	0.058	0.084	0.141	0.113	0.01	0.007	0.026	0.038
FDS	Atlantic cod	0.003	0.004	0	0.014	0.02	0.01	0.016	0.138	0.01	0.071	0.068
FDB	Silver hake	0.009	0.023	0.032	0.05	0.036	0.102	0.045	0.014	0.04	0.007	0.085
FMM	Migratory mesopelagics	0	0	0.188	0	0.107	0.12	0	0	0.2	0	0.1
FPL	Atlantic mackerel	0.1	0.1	0.105	0.284	0.1	0.23	0.03	0.01	0.03	0.001	0
FPS	Atlantic herring	0.1	0.1	0.105	0.284	0.1	0.23	0.03	0.01	0.03	0.001	0
FVD	White hake	0	0	0.003	0.002	0.004	0.007	0.008	0.018	0.009	0.001	0.032
FVS	Bluefish	0.299	0.162	0.088	0.108	0.095	0.073	0.063	0.01	0	0.102	0
FVB	Other piscivores	0.026	0.019	0.01	0.038	0.084	0.054	0.064	0.064	0.039	0.064	0.047
FVT	Large piscivores	0	0	0.101	0.003	0.105	0.2	0.01	0.05	0.2	0.001	0
PIN	Pinnipeds	0	0	0	0	0	0	0.061	0.05	0.01	0.3	0.02
SB	Seabirds	0.022	0.022	0.022	0.022	0.039	0.039	0.039	0.087	0.087	0.087	0.087
SHD	Other demersal sharks	0.348	0.143	0.017	0.051	0.073	0.026	0.006	0.187	0	0.001	0.001
SHB	Spiny dogfish	0.1	0.1	0.105	0.284	0.1	0.23	0.03	0.01	0.03	0.001	0
SHP	Pelagic sharks	0.1	0.1	0.105	0.284	0.1	0.23	0.03	0.01	0.03	0.001	0
SSK	Skates and rays	0.049	0.047	0.008	0.02	0.112	0.039	0.055	0.119	0.018	0.106	0.085
REP	Reptiles	0.299	0.162	0.088	0.108	0.095	0.073	0.063	0.01	0	0.102	0
WHB	Baleen whales	0.008	0.008	0.008	0.008	0.008	0.026	0.026	0.029	0.026	0.081	0.081
WHT	Toothed whales	0.023	0.023	0.023	0.023	0.043	0.043	0.043	0.09	0.09	0.09	0.09
CEP	Squid	0.083	0.083	0.083	0.083	0.083	0.095	0.083	0.083	0.11	0.03	0.03
PWN	Shrimp	0	0	0.001	0	0.001	0	0	0.004	0.001	0.202	0.072

Table A8, continued. Distribution of juvenile stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from January to March.

CODE	GROUP	REGIONS										
		12	13	14	15	16	17	18	19	20	21	22
FBP	Benthopelagics	0.026	0	0	0.001	0.001	0	0.001	0.011	0	0	0.049
FDD	Goosefish	0.077	0.05	0.052	0.068	0.068	0.041	0.022	0.018	0.087	0.045	0.031
FDC	Miscellaneous demersals	0.064	0.046	0.026	0.02	0.113	0.122	0.044	0.031	0.099	0.086	0.009
FDO	Haddock	0.057	0.094	0.025	0.02	0.014	0.027	0.152	0.108	0.073	0.061	0
FDF	Yellowtail flounder	0.029	0.002	0.003	0.004	0	0	0.011	0.097	0.001	0	0.035
FDE	Shallow demersal fish	0.04	0.003	0.198	0.119	0.012	0.009	0.011	0.013	0.009	0.01	0.016
FDS	Atlantic cod	0.11	0.082	0.075	0.052	0.054	0.023	0.068	0.067	0.06	0.048	0.007
FDB	Silver hake	0.077	0.037	0.073	0.04	0.062	0.04	0.01	0.017	0.094	0.085	0.022
FMM	Migratory mesopelagics	0.035	0	0.2	0	0	0	0	0	0.05	0	0
FPL	Atlantic mackerel	0	0	0.01	0	0	0	0	0	0	0	0
FPS	Atlantic herring	0	0	0.01	0	0	0	0	0	0	0	0
FVD	White hake	0.08	0.037	0.149	0.072	0.166	0.172	0.019	0.005	0.113	0.103	0
FVS	Bluefish	0	0	0	0	0	0	0	0	0	0	0
FVB	Other piscivores	0.068	0.003	0.066	0.066	0.045	0.033	0.028	0.048	0.039	0.027	0.068
FVT	Large piscivores	0	0	0.17	0.16	0	0	0	0	0	0	0
PIN	Pinnipeds	0.104	0.001	0	0	0.15	0.15	0.154	0	0	0	0
SB	Seabirds	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.087	0.036	0.036	0.039
SHD	Other demersal sharks	0	0	0	0	0	0	0	0	0	0	0.147
SHB	Spiny dogfish	0	0	0.01	0	0	0	0	0	0	0	0
SHP	Pelagic sharks	0	0	0.01	0	0	0	0	0	0	0	0
SSK	Skates and rays	0.021	0.023	0.019	0.014	0.042	0.023	0.018	0.064	0.041	0.033	0.044
REP	Reptiles	0	0	0	0	0	0	0	0	0	0	0
WHB	Baleen whales	0.029	0.029	0.029	0.029	0.081	0.081	0.081	0.081	0.081	0.081	0.081
WHT	Toothed whales	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.09	0.034	0.034	0.023
CEP	Squid	0.03	0.03	0.03	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
PWN	Shrimp	0.012	0	0.001	0.001	0.515	0.049	0.077	0.029	0.023	0.006	0.006

Table A9. Distribution of juvenile stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from April to June.

CODE	GROUP	REGIONS										
		1	2	3	4	5	6	7	8	9	10	11
FBP	Benthopelagics	0.139	0.071	0.226	0.087	0.069	0.093	0.107	0.08	0.021	0.01	0.008
FDD	Goosefish	0.014	0.026	0.05	0.048	0.054	0.082	0.041	0.051	0.019	0.014	0.042
FDC	Miscellaneous demersals	0.047	0.03	0.05	0.01	0.052	0.025	0.025	0.03	0.015	0.017	0.039
FDO	Haddock	0	0	0	0	0	0	0.011	0.102	0.017	0.12	0.119
FDF	Yellowtail flounder	0.004	0.035	0.013	0.093	0.204	0.116	0.108	0.033	0.036	0.11	0.066
FDE	Shallow demersal fish	0.019	0.038	0.026	0.058	0.084	0.141	0.113	0.01	0.007	0.026	0.038
FDS	Atlantic cod	0.003	0.004	0	0.014	0.02	0.01	0.016	0.138	0.01	0.071	0.068
FDB	Silver hake	0.009	0.023	0.032	0.05	0.036	0.102	0.045	0.014	0.04	0.007	0.085
FMM	Migratory mesopelagics	0	0	0.188	0	0.107	0.12	0	0	0.2	0	0.1
FPL	Atlantic mackerel	0.001	0.001	0.001	0.234	0.1	0.268	0.1	0.07	0.1	0.02	0.005
FPS	Atlantic herring	0.001	0.001	0.001	0.234	0.1	0.268	0.1	0.07	0.1	0.02	0.005
FVD	White hake	0	0	0.001	0.002	0.004	0.007	0.008	0.018	0.009	0.001	0.032
FVS	Bluefish	0.202	0.042	0.038	0.14	0.095	0.073	0.123	0.01	0	0.102	0.056
FVB	Other piscivores	0.026	0.019	0.01	0.038	0.084	0.054	0.064	0.084	0.039	0.064	0.047
FVT	Large piscivores	0	0	0.101	0.003	0.105	0.1	0.01	0.05	0.25	0.001	0
PIN	Pinnipeds	0	0	0	0	0	0	0.061	0.05	0.01	0.3	0.02
SB	Seabirds	0.022	0.022	0.022	0.022	0.039	0.039	0.039	0.087	0.087	0.087	0.087
SHD	Other demersal sharks	0.348	0.143	0.017	0.051	0.073	0.026	0.006	0.187	0	0.001	0.001
SHB	Spiny dogfish	0.001	0.001	0.001	0.234	0.1	0.268	0.1	0.07	0.1	0.02	0.005
SHP	Pelagic sharks	0.001	0.001	0.001	0.234	0.1	0.268	0.1	0.07	0.1	0.02	0.005
SSK	Skates and rays	0.049	0.047	0.008	0.02	0.112	0.039	0.055	0.119	0.018	0.106	0.085
REP	Reptiles	0.202	0.042	0.038	0.14	0.095	0.073	0.123	0.01	0	0.102	0.056
WHB	Baleen whales	0.008	0.008	0.008	0.008	0.008	0.026	0.026	0.029	0.026	0.081	0.081
WHT	Toothed whales	0.023	0.023	0.023	0.023	0.043	0.043	0.043	0.09	0.09	0.09	0.09
CEP	Squid	0.071	0.072	0.072	0.072	0.072	0.083	0.072	0.072	0.1	0.05	0.05
PWN	Shrimp	0	0	0.001	0	0.001	0	0	0.004	0.001	0.202	0.072

Table A9, continued. Distribution of juvenile stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from April to June.

CODE	GROUP	REGIONS										
		12	13	14	15	16	17	18	19	20	21	22
FBP	Benthopelagics	0.026	0	0	0.001	0.001	0	0.001	0.011	0	0	0.049
FDD	Goosefish	0.077	0.05	0.052	0.068	0.068	0.041	0.022	0.018	0.087	0.045	0.031
FDC	Miscellaneous demersals	0.064	0.046	0.026	0.02	0.113	0.122	0.044	0.031	0.099	0.086	0.009
FDO	Haddock	0.057	0.094	0.025	0.02	0.014	0.027	0.152	0.108	0.073	0.061	0
FDF	Yellowtail flounder	0.029	0.002	0.003	0.004	0	0	0.011	0.097	0.001	0	0.035
FDE	Shallow demersal fish	0.04	0.003	0.198	0.119	0.012	0.009	0.011	0.013	0.009	0.01	0.016
FDS	Atlantic cod	0.11	0.082	0.075	0.052	0.054	0.023	0.068	0.067	0.06	0.048	0.007
FDB	Silver hake	0.077	0.037	0.073	0.04	0.062	0.04	0.01	0.017	0.094	0.085	0.022
FMM	Migratory mesopelagics	0.035	0	0.2	0	0	0	0	0	0.05	0	0
FPL	Atlantic mackerel	0.025	0	0.07	0.001	0.003	0	0.001	0	0	0	0
FPS	Atlantic herring	0.025	0	0.07	0.001	0.003	0	0.001	0	0	0	0
FVD	White hake	0.08	0.037	0.149	0.072	0.166	0.172	0.019	0.005	0.113	0.103	0
FVS	Bluefish	0	0	0.002	0.001	0	0	0	0.013	0	0	0.103
FVB	Other piscivores	0.068	0.003	0.066	0.066	0.045	0.033	0.028	0.038	0.039	0.017	0.068
FVT	Large piscivores	0	0	0.22	0.16	0	0	0	0	0	0	0
PIN	Pinnipeds	0.104	0.001	0	0	0.15	0.15	0.154	0	0	0	0
SB	Seabirds	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.087	0.036	0.036	0.039
SHD	Other demersal sharks	0	0	0	0	0	0	0	0	0	0	0.147
SHB	Spiny dogfish	0.025	0	0.07	0.001	0.003	0	0.001	0	0	0	0
SHP	Pelagic sharks	0.025	0	0.07	0.001	0.003	0	0.001	0	0	0	0
SSK	Skates and rays	0.021	0.023	0.019	0.014	0.042	0.023	0.018	0.064	0.041	0.033	0.044
REP	Reptiles	0	0	0.002	0.001	0	0	0	0.013	0	0	0.103
WHB	Baleen whales	0.029	0.029	0.029	0.029	0.081	0.081	0.081	0.081	0.081	0.081	0.081
WHT	Toothed whales	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.09	0.034	0.034	0.023
CEP	Squid	0.05	0.05	0.05	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
PWN	Shrimp	0.012	0	0.001	0.001	0.515	0.049	0.077	0.029	0.023	0.006	0.006

Table A10. Distribution of juvenile stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from July to September.

CODE	GROUP	REGIONS										
		1	2	3	4	5	6	7	8	9	10	11
FBP	Benthopelagics	0.139	0.071	0.226	0.087	0.069	0.093	0.107	0.08	0.021	0.01	0.008
FDD	Goosefish	0.014	0.026	0.05	0.048	0.054	0.082	0.041	0.051	0.019	0.014	0.042
FDC	Miscellaneous demersals	0.047	0.03	0.05	0.01	0.052	0.025	0.025	0.03	0.015	0.017	0.039
FDO	Haddock	0	0	0	0	0	0	0.011	0.102	0.017	0.12	0.119
FDF	Yellowtail flounder	0.004	0.035	0.013	0.093	0.204	0.116	0.108	0.033	0.036	0.11	0.066
FDE	Shallow demersal fish	0.019	0.038	0.026	0.058	0.084	0.141	0.113	0.01	0.007	0.026	0.038
FDS	Atlantic cod	0.003	0.004	0	0.014	0.02	0.01	0.016	0.138	0.01	0.071	0.068
FDB	Silver hake	0.009	0.023	0.032	0.05	0.036	0.102	0.045	0.014	0.04	0.007	0.085
FMM	Migratory mesopelagics	0	0	0.188	0	0.107	0.12	0	0	0.2	0	0.1
FPL	Atlantic mackerel	0	0	0	0	0	0	0	0.001	0.001	0.08	0.03
FPS	Atlantic herring	0	0	0	0	0	0	0	0.001	0.001	0.08	0.03
FVD	White hake	0	0	0.003	0.002	0.004	0.007	0.008	0.018	0.009	0.001	0.032
FVS	Bluefish	0.203	0.042	0.038	0.14	0.095	0.073	0.123	0.01	0	0.102	0.056
FVB	Other piscivores	0.026	0.019	0.01	0.038	0.084	0.054	0.064	0.064	0.039	0.064	0.047
FVT	Large piscivores	0	0	0.101	0.003	0.105	0.1	0.01	0.05	0.25	0.001	0
PIN	Pinnipeds	0	0	0	0	0	0	0.061	0.05	0.01	0.3	0.02
SB	Seabirds	0.022	0.022	0.022	0.022	0.039	0.039	0.039	0.087	0.087	0.087	0.087
SHD	Other demersal sharks	0.348	0.143	0.017	0.051	0.073	0.026	0.006	0.187	0	0.001	0.001
SHB	Spiny dogfish	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.001	0.07	0.08	0.03
SHP	Pelagic sharks	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.001	0.07	0.08	0.03
SSK	Skates and rays	0.049	0.047	0.008	0.02	0.112	0.039	0.055	0.119	0.018	0.106	0.085
REP	Reptiles	0.202	0.042	0.038	0.14	0.095	0.073	0.123	0.01	0	0.102	0.056
WHB	Baleen whales	0.008	0.008	0.008	0.008	0.008	0.026	0.026	0.029	0.026	0.081	0.081
WHT	Toothed whales	0.023	0.023	0.023	0.023	0.043	0.043	0.043	0.09	0.09	0.09	0.09
CEP	Squid	0.071	0.072	0.072	0.072	0.072	0.083	0.072	0.072	0.1	0.05	0.05
PWN	Shrimp	0	0	0.001	0	0.001	0	0	0.004	0.001	0.202	0.072

Table A10, continued. Distribution of juvenile stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from July to September.

CODE	GROUP	REGIONS										
		12	13	14	15	16	17	18	19	20	21	22
FBP	Benthopelagics	0.026	0	0	0.001	0.001	0	0.001	0.011	0	0	0.049
FDD	Goosefish	0.077	0.05	0.052	0.068	0.068	0.041	0.022	0.018	0.087	0.045	0.031
FDC	Miscellaneous demersals	0.064	0.046	0.026	0.02	0.113	0.122	0.044	0.031	0.099	0.086	0.009
FDO	Haddock	0.057	0.094	0	0.02	0.014	0.027	0.152	0.108	0.073	0.061	0
FDF	Yellowtail flounder	0.029	0.002	0.003	0.004	0	0	0.011	0.097	0.001	0	0.035
FDE	Shallow demersal fish	0.04	0.003	0.198	0.119	0.012	0.009	0.011	0.013	0.009	0.01	0.016
FDS	Atlantic cod	0.11	0.082	0.075	0.052	0.054	0.023	0.068	0.067	0.06	0.048	0.007
FDB	Silver hake	0.077	0.037	0.073	0.04	0.062	0.04	0.01	0.017	0.094	0.085	0.022
FMM	Migratory mesopelagics	0.035	0	0.2	0	0	0	0	0	0.05	0	0
FPL	Atlantic mackerel	0.09	0.08	0.06	0.227	0.02	0.05	0.05	0.021	0.05	0.13	0.11
FPS	Atlantic herring	0.09	0.08	0.06	0.227	0.02	0.05	0.05	0.021	0.05	0.13	0.11
FVD	White hake	0.08	0.037	0.149	0.072	0.166	0.172	0.019	0.005	0.113	0.103	0
FVS	Bluefish	0	0	0.002	0.001	0	0	0	0.013	0	0	0.103
FVB	Other piscivores	0.068	0.003	0.066	0.066	0.045	0.033	0.028	0.048	0.039	0.027	0.068
FVT	Large piscivores	0	0	0.22	0.16	0	0	0	0	0	0	0
PIN	Pinnipeds	0.104	0.001	0	0	0.15	0.15	0.154	0	0	0	0
SB	Seabirds	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.087	0.036	0.036	0.039
SHD	Other demersal sharks	0	0	0	0	0	0	0	0	0	0	0.147
SHB	Spiny dogfish	0.09	0.08	0.08	0.12	0.02	0.05	0.05	0.021	0.04	0.1	0.1
SHP	Pelagic sharks	0.09	0.08	0.08	0.12	0.02	0.05	0.05	0.021	0.04	0.1	0.1
SSK	Skates and rays	0.021	0.023	0.019	0.014	0.042	0.023	0.018	0.064	0.041	0.033	0.044
REP	Reptiles	0	0	0.002	0.001	0	0	0	0.013	0	0	0.103
WHB	Baleen whales	0.029	0.029	0.029	0.029	0.081	0.081	0.081	0.081	0.081	0.081	0.081
WHT	Toothed whales	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.09	0.034	0.034	0.023
CEP	Squid	0.05	0.05	0.05	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
PWN	Shrimp	0.012	0	0.001	0.001	0.515	0.049	0.077	0.029	0.023	0.006	0.006

Table A11. Distribution of juvenile stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from October to December.

CODE	GROUP	REGIONS										
		1	2	3	4	5	6	7	8	9	10	11
FBP	Benthopelagics	0.139	0.071	0.226	0.087	0.069	0.093	0.107	0.08	0.021	0.01	0.008
FDD	Goosefish	0.014	0.026	0.05	0.048	0.054	0.082	0.041	0.051	0.019	0.014	0.042
FDC	Miscellaneous demersals	0.047	0.03	0.05	0.01	0.052	0.025	0.025	0.03	0.015	0.017	0.039
FDO	Haddock	0	0	0	0	0	0	0.011	0.102	0.017	0.12	0.119
FDF	Yellowtail flounder	0.004	0.035	0.013	0.093	0.204	0.116	0.108	0.033	0.036	0.11	0.066
FDE	Shallow demersal fish	0.019	0.038	0.026	0.058	0.084	0.141	0.113	0.01	0.007	0.026	0.038
FDS	Atlantic cod	0.003	0.004	0	0.014	0.02	0.01	0.016	0.138	0.01	0.071	0.068
FDB	Silver hake	0.009	0.023	0.032	0.05	0.036	0.102	0.045	0.014	0.04	0.007	0.085
FMM	Migratory mesopelagics	0	0	0.188	0	0.107	0.12	0	0	0.2	0	0.1
FPL	Atlantic mackerel	0.039	0.067	0.105	0.284	0.07	0.268	0.029	0.004	0.036	0.012	0.005
FPS	Atlantic herring	0.036	0.03	0.004	0.05	0.044	0.149	0.028	0.081	0.033	0.011	0.091
FVD	White hake	0	0	0.001	0.002	0.004	0.007	0.008	0.018	0.009	0.001	0.032
FVS	Bluefish	0.299	0.162	0.088	0.108	0.095	0.073	0.063	0.01	0	0.102	0
FVB	Other piscivores	0.026	0.019	0.01	0.038	0.084	0.054	0.064	0.064	0.039	0.064	0.047
FVT	Large piscivores	0	0	0.101	0.003	0.105	0.2	0.01	0.05	0.2	0.001	0
PIN	Pinnipeds	0	0	0	0	0	0	0.061	0.05	0.01	0.3	0.02
SB	Seabirds	0.022	0.022	0.022	0.022	0.039	0.039	0.039	0.087	0.087	0.087	0.087
SHD	Other demersal sharks	0.348	0.143	0.017	0.051	0.073	0.026	0.006	0.187	0	0.001	0.001
SHB	Spiny dogfish	0.039	0.067	0.105	0.284	0.07	0.268	0.029	0.004	0.036	0.012	0.005
SHP	Pelagic sharks	0.039	0.067	0.105	0.284	0.07	0.268	0.029	0.004	0.036	0.012	0.005
SSK	Skates and rays	0.049	0.047	0.008	0.02	0.112	0.039	0.055	0.119	0.018	0.106	0.085
REP	Reptiles	0.299	0.162	0.088	0.108	0.095	0.073	0.063	0.01	0	0.102	0
WHB	Baleen whales	0.008	0.008	0.008	0.008	0.008	0.026	0.026	0.029	0.026	0.081	0.081
WHT	Toothed whales	0.023	0.023	0.023	0.023	0.043	0.043	0.043	0.09	0.09	0.09	0.09
CEP	Squid	0.083	0.083	0.083	0.083	0.083	0.095	0.083	0.083	0.11	0.03	0.03
PWN	Shrimp	0	0	0.001	0	0.001	0	0	0.004	0.001	0.202	0.072

Table A11, continued. Distribution of juvenile stages of each vertebrate and mobile invertebrate group, given as a proportion, for each region (See Figure 5) in Atlantis NEUS at each time step, from October to December.

CODE	GROUP	REGIONS										
		12	13	14	15	16	17	18	19	20	21	22
FBP	Benthopelagics	0.026	0	0	0.001	0.001	0	0.001	0.011	0	0	0.049
FDD	Goosefish	0.077	0.05	0.052	0.068	0.068	0.041	0.022	0.018	0.087	0.045	0.031
FDC	Miscellaneous demersals	0.064	0.046	0.026	0.02	0.113	0.122	0.044	0.031	0.099	0.086	0.009
FDO	Haddock	0.057	0.094	0.025	0.02	0.014	0.027	0.152	0.108	0.073	0.061	0
FDF	Yellowtail flounder	0.029	0.002	0.003	0.004	0	0	0.011	0.097	0.001	0	0.035
FDE	Shallow demersal fish	0.04	0.003	0.198	0.119	0.012	0.009	0.011	0.013	0.009	0.01	0.016
FDS	Atlantic cod	0.11	0.082	0.075	0.052	0.054	0.023	0.068	0.067	0.06	0.048	0.007
FDB	Silver hake	0.077	0.037	0.073	0.04	0.062	0.04	0.01	0.017	0.094	0.085	0.022
FMM	Migratory mesopelagics	0.035	0	0.2	0	0	0	0	0	0.05	0	0
FPL	Atlantic mackerel	0.025	0	0.028	0.001	0.003	0.002	0.001	0.021	0	0	0
FPS	Atlantic herring	0.29	0.006	0.004	0.009	0.011	0.008	0.026	0.039	0.02	0.004	0.026
FVD	White hake	0.08	0.037	0.149	0.072	0.166	0.172	0.019	0.005	0.113	0.103	0
FVS	Bluefish	0	0	0	0	0	0	0	0	0	0	0
FVB	Other piscivores	0.068	0.003	0.066	0.066	0.045	0.033	0.028	0.048	0.039	0.027	0.068
FVT	Large piscivores	0	0	0.17	0.16	0	0	0	0	0	0	0
PIN	Pinnipeds	0.104	0.001	0	0	0.15	0.15	0.154	0	0	0	0
SB	Seabirds	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.087	0.036	0.036	0.039
SHD	Other demersal sharks	0	0	0	0	0	0	0	0	0	0	0.147
SHB	Spiny dogfish	0.025	0	0.028	0.001	0.003	0.002	0.001	0.021	0	0	0
SHP	Pelagic sharks	0.025	0	0.028	0.001	0.003	0.002	0.001	0.021	0	0	0
SSK	Skates and rays	0.021	0.023	0.019	0.014	0.042	0.023	0.018	0.064	0.041	0.033	0.044
REP	Reptiles	0	0	0	0	0	0	0	0	0	0	0
WHB	Baleen whales	0.029	0.029	0.029	0.029	0.081	0.081	0.081	0.081	0.081	0.081	0.081
WHT	Toothed whales	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.09	0.034	0.034	0.023
CEP	Squid	0.03	0.03	0.03	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
PWN	Shrimp	0.012	0	0.001	0.001	0.515	0.049	0.077	0.029	0.023	0.006	0.006

Table A12. Growth rates (mg / day) for vertebrate groups in Atlantis NEUS for each age class. Each class is the maximum age in Table A1 divided by 10 (number of stages), distinct for each group.

CODE	GROUP	AGE CLASS									
		1	2	3	4	5	6	7	8	9	10
FPL	Atlantic mackerel	0.68	0.687	4.822	16.88	18.323	20.368	20.382	20.39	20.398	20.399
FPS	Atlantic herring	3.374	3.032	3.602	4.853	5.346	5.425	6.46	6.465	6.466	6.47
FVD	White hake	2.012	5.441	18.643	27.782	75.584	138.218	228.255	308.063	457.33	569
FVS	Bluefish	3.022	45.739	80.307	195.188	195.841	195.673	195.018	195.023	195.216	205
FVT	Large piscivores	2.667	666.667	1266.667	3760.667	5796.667	8806.667	8836.667	8806.667	8816.667	8826.667
FVB	Other piscivores	3.312	4.126	5.77	7.447	18.7	29.665	40.663	40.702	40.9	41.6
FMM	Migratory mesopelagics	0.0307	0.0173	0.00487	0.00487	0.00487	0.00487	0.004873	0.00487	0.00487	0.00487
FBP	Benthopelagics	0.8	1	1.2	1.7	1.9	2.1	2.2	2.9	2.9	2.9
FDD	Goosefish	1.84	5.048	6.669	18.428	29.21	75.896	109.143	152.755	166.47	150
FDS	Atlantic cod	2.766	33.826	78.983	155.83	252.431	305.03	305	304.366	310.183	315
FDB	Silver hake	0.1255	2.345	3.13	6.878	15.069	28.334	44.06	45	46.873	47
FDC	Miscellaneous demersals	0.73	3.902	5.88	8.412	12.319	18.033	21.9	20.949	20.5	20
FDO	Haddock	2.1	20.112	28.615	48.252	55.844	60.49	61.625	61.0173	61	61.9
FDE	Shallow demersal fish	6.03	9.309	9.511	9.3	9.289	9.315	9.315	9.5	9.521	9.59
FDF	Yellowtail flounder	0.754	2.863	5.584	7.75	11.232	15.656	15.391	15.324	15.762	15.5
SHD	Other demersal sharks	1	9	10	15	15	20	20	20	20	20
SHP	Pelagic sharks	3	52	300	1230.5	1550.5	1850.5	1850.5	1850.5	2550.5	2550.5
SHB	Spiny dogfish	0.5	10.5	25.5	80.5	270.5	320.5	460.5	520.5	520.5	520.5
SSK	Skates and rays	3	9	10	26	40	50	50	50	150	1500
SB	Seabirds	200	400	500	500	500	800	800	800	800	800
REP	Reptiles	10	150	100	100	100	150	205	205	205	205
PIN	Pinnipeds	100	500	500	500	500	500	500	500	500	500
WHB	Baleen whales	2000000	3500000	3500000	3500000	3500000	3500000	3500000	3500000	3500000	3500000
WHT	Toothed whales	52000	18000	18000	18000	18000	18000	18000	18000	18000	18000

Table A13. Growth rates for invertebrate groups in Atlantis NEUS.

CODE	GROUP	Rate (mg N / d)
ZG	Gelatinous zooplankton	0.017
ZL	Carnivorous zooplankton	0.1
ZM	Copepods	0.18
ZS	Microzooplankton	0.55
BFS	Sea scallop	0.05
BFF	Other benthic filter feeder	0.0035
BD	Deposit feeder	0.004
BC	Benthic carnivore	0.0008
BG	Benthic grazer	0.002
BMS	Shallow macrozoobenthos	0.0001
BML	Lobster	0.00012
BO	Meiobenthos	0.04
PB	Pelagic bacteria	1.5
BB	Sediment bacteria	1.5
CEP	Squid	0.0444
jCEP	Juv. Squid	0.046
PWN	Shrimp	0.003043
jPWN	Juv. Shrimp	0.003043

Table A14. Consumption parameters (a in Equation 69) in the calibrated model for predation on some fish groups. Prey groups are listed by column. A value of 0 indicates cases where that predator does not eat that prey. In the left hand column, j-->j signifies juvenile predation on juveniles, a-->j signifies adult predation on juveniles, j-->a signifies juvenile predation on adults, and a-->a signifies adult predation on adults

PREDATOR			PREY								
Stages	Code	Group	FPL	FPS	FVD	FVS	FVB	FVT	FMM	FBP	FDD
j-->j	FPL	Atlantic mackerel	0.0001	0.00005	0	0	0.008	0	0	0.01	0
a-->j	FPL	Atlantic mackerel	0.0001	0.00005	0	0	0.01	0	0	0.007	0
j-->a	FPL	Atlantic mackerel	0.00001	0	0	0	0.0005	0	0	0.01	0
a-->a	FPL	Atlantic mackerel	0.00001	0	0	0	0.0005	0	0	0.01	0
j-->j	FPS	Atlantic herring	0	0.0005	0	0	0	0	0.008	0.008	0
a-->j	FPS	Atlantic herring	0	0.00005	0	0	0	0	0.008	0.004	0
j-->a	FPS	Atlantic herring	0	0.0001	0	0	0	0	0.003	0.00165	0
a-->a	FPS	Atlantic herring	0	0	0	0	0	0	0.003	0.0001	0
j-->j	FVD	White hake	0.15	0.08	0.035	0	0.15	0	0.025	0.05	0.015
a-->j	FVD	White hake	0.03	0.08	0.035	0	0.1	0	0.025	0.04	0.06
j-->a	FVD	White hake	0.01	0.075	0.035	0	0.1	0	0.03	0.2	0.0025
a-->a	FVD	White hake	0.01	0.075	0.035	0	0.1	0	0.03	0.2	0.045
j-->j	FVS	Bluefish	0.06	0.02	0.00225	0.0095	0.026	0	0.1	0.04	0
a-->j	FVS	Bluefish	0.06	0.02	0.0025	0.008	0.09	0	0.1	0.04	0
j-->a	FVS	Bluefish	0.007	0.005	0.005	0.0017	0.026	0	0.15	0.03	0
a-->a	FVS	Bluefish	0.007	0.005	0.005	0.0007	0.08	0	0.15	0.03	0
j-->j	FVB	Other piscivores	0.085	0.008	0.007	0.0525	0.013	0	0.02	0.05	0
a-->j	FVB	Other piscivores	0.085	0.008	0.007	0.05	0.015	0	0.02	0.05	0.03
j-->a	FVB	Other piscivores	0.005	0.008	0.017	0.015	0.05	0	0.06	0.12	0
a-->a	FVB	Other piscivores	0.005	0.008	0.009	0.025	0.05	0	0.06	0.15	0.015
j-->j	FVT	Large piscivores	0.003	0.09	0	0	0	0.02	0.1	0.08	0
a-->j	FVT	Large piscivores	0.003	0.09	0	0	0	0.03	0.1	0.08	0
j-->a	FVT	Large piscivores	0.01	0.04	0	0	0	0.003	0.2	0.06	0
a-->a	FVT	Large piscivores	0.01	0.04	0	0	0	0.02	0.2	0.06	0
j-->j	FMM	Migratory mesopelagics	0	0	0	0	0	0	0	0	0
a-->j	FMM	Migratory mesopelagics	0	0	0	0	0	0	0	0	0
j-->a	FMM	Migratory mesopelagics	0	0	0	0	0	0	0	0	0
a-->a	FMM	Migratory mesopelagics	0	0	0	0	0	0	0	0	0
j-->j	FBP	Benthopelagics	0	0	0	0	0	0	0	0	0
a-->j	FBP	Benthopelagics	0	0	0	0	0	0	0	0	0
j-->a	FBP	Benthopelagics	0	0	0	0	0	0	0	0	0
a-->a	FBP	Benthopelagics	0	0	0	0	0	0	0	0	0
j-->j	FDD	Goosefish	0.005	0.05	0.004	0	0.05	0	0.06	0.02	0.01
a-->j	FDD	Goosefish	0.0006	0.05	0.0045	0	0.08	0	0.06	0.02	0.01
j-->a	FDD	Goosefish	0.005	0.01	0.01	0	0.05	0	0.08	0.005	0.004
a-->a	FDD	Goosefish	0.005	0.01	0.0035	0	0.06	0	0.08	0.005	0.0075
j-->j	FDE	Shallow demersal fish	0	0	0	0	0	0	0	0	0
a-->j	FDE	Shallow demersal fish	0	0	0	0	0	0	0	0	0
j-->a	FDE	Shallow demersal fish	0	0	0	0	0	0	0	0	0
a-->a	FDE	Shallow demersal fish	0	0	0	0	0	0	0	0	0
j-->j	FDS	Atlantic cod	0.0048	0.07	0.0045	0.008	0.05	0	0.06	0.065	0.03
a-->j	FDS	Atlantic cod	0.048	0.07	0.008	0.008	0.03	0	0.06	0.065	0.03
j-->a	FDS	Atlantic cod	0.005	0.02	0.0035	0.0015	0.05	0	0.03	0.28	0.03
a-->a	FDS	Atlantic cod	0.05	0.02	0.0035	0.0025	0.02	0	0.03	0.28	0.025
j-->j	FDB	Silver hake	0.028	0.005	0	0	0.005	0	0.06	0.04	0
a-->j	FDB	Silver hake	0.033	0.005	0	0	0.005	0	0.06	0.04	0
j-->a	FDB	Silver hake	0.035	0.003	0	0	0.005	0	0.07	0.008	0
a-->a	FDB	Silver hake	0.035	0.005	0	0	0.005	0	0.07	0.007	0
j-->j	FDC	Miscellaneous demersals	0.006	0.004	0	0.007	0.021	0	0.01	0.02	0.012
a-->j	FDC	Miscellaneous demersals	0.006	0.004	0	0.0035	0.025	0	0.01	0.02	0.012

Table A14, continued. Consumption parameters (a in Equation 69) in the calibrated model for predation on some fish groups. Prey groups are listed by column. A value of 0 indicates cases where that predator does not eat that prey. In the left hand column, j-->j signifies juvenile predation on juveniles, a-->j signifies adult predation on juveniles, j-->a signifies juvenile predation on adults, and a-->a signifies adult predation on adults

PREDATOR			PREY								
Stages	Code	Group	FPL	FPS	FVD	FVS	FVB	FVT	FMM	FBP	FDD
j-->a	FDC	Miscellaneous demersals	0.008	0.0025	0	0.0005	0.0275	0	0.02	0.03	0.005
a-->a	FDC	Miscellaneous demersals	0.008	0.0025	0	0.0015	0.0275	0	0.02	0.03	0.005
j-->j	FDO	Haddock	0.13	0	0	0	0.00393	0	0.01	0	0
a-->j	FDO	Haddock	0.13	0	0	0	0.0045	0	0.01	0	0
j-->a	FDO	Haddock	0.01	0	0	0	0.00393	0	0.008	0	0
a-->a	FDO	Haddock	0.01	0	0	0	0.00393	0	0.008	0	0
j-->j	FDF	Yellowtail flounder	0	0	0	0	0	0	0	0	0
a-->j	FDF	Yellowtail flounder	0	0	0	0	0	0	0	0	0
j-->a	FDF	Yellowtail flounder	0	0	0	0	0	0	0	0	0
a-->a	FDF	Yellowtail flounder	0	0	0	0	0	0	0	0	0
j-->j	SHB	Spiny dogfish	0.023	0.0003	0.0004	0.04	0.0025	0	0.01	0.015	0.0025
a-->j	SHB	Spiny dogfish	0.008	0.0003	0.0005	0.04	0.0025	0	0.01	0.015	0.0025
j-->a	SHB	Spiny dogfish	0.001	0.0001	0.0007	0.00015	0.001	0	0.015	0.05	0.0008
a-->a	SHB	Spiny dogfish	0.001	0.0001	0.0007	0.0005	0.001	0	0.015	0.05	0.0015
j-->j	SHD	Other demersal sharks	0.09	0.14	0.0007	0.31	0.08	0	0.07	0.25	0.003
a-->j	SHD	Other demersal sharks	0.09	0.12	0.001	0.27	0.08	0	0.1	0.25	0.012
j-->a	SHD	Other demersal sharks	0.1	0.07	0.0005	0.015	0.081	0	0.5	0.3	0.075
a-->a	SHD	Other demersal sharks	0.1	0.055	0.0005	0.015	0.081	0	0.5	0.35	0.075
j-->j	SHP	Pelagic sharks	0.11	0.1	0	0.46	0.075	0.15	0.1	0.3	0.125
a-->j	SHP	Pelagic sharks	0.09	0.1	0	0.46	0.075	0.3	0.1	0.7	0.125
j-->a	SHP	Pelagic sharks	0.08	0.2	0	0.005	0.06	0.15	0.9	0.3	0.15
a-->a	SHP	Pelagic sharks	0.08	0.2	0	0.02	0.06	0.6	0.7	0.7	0.15
j-->j	SSK	Skates and rays	0.04	0.1	0	0	0.08	0	0.1	0.01	0.015
a-->j	SSK	Skates and rays	0.025	0.1	0	0	0.065	0	0.1	0.01	0.017
j-->a	SSK	Skates and rays	0.0025	0.06	0	0	0.06	0	0.08	0.15	0.0275
a-->a	SSK	Skates and rays	0.004	0.06	0	0	0.07	0	0.08	0.15	0.0275
j-->j	SB	Seabirds	0.23	0.5	0	0.31	0.01	0	0	0.3	0
a-->j	SB	Seabirds	0.23	0.5	0	0.31	0.01	0	0	0.3	0
j-->a	SB	Seabirds	0.1	0.1	0	0.015	0.015	0	0	0.65	0
a-->a	SB	Seabirds	0.1	0.1	0	0.015	0.015	0	0	0.65	0
j-->j	PIN	Pinnipeds	0.1	0.2	0	0.3	0.01	0.3	0.1	0.75	0
a-->j	PIN	Pinnipeds	0.1	0.2	0	0.3	0.01	0.3	0.1	0.75	0
j-->a	PIN	Pinnipeds	0.08	0.05	0	0.015	0.015	0.1	0.9	0.85	0
a-->a	PIN	Pinnipeds	0.08	0.05	0	0.07	0.03	0.1	0.9	0.85	0
j-->j	REP	Reptiles	0	0	0	0	0	0	0	0	0
a-->j	REP	Reptiles	0	0	0	0	0	0	0	0	0
j-->a	REP	Reptiles	0	0	0	0	0	0	0	0	0
a-->a	REP	Reptiles	0	0	0	0	0	0	0	0	0
j-->j	WHB	Baleen whales	0	0.025	0	0	0	0	0.08	0.02	0
a-->j	WHB	Baleen whales	0	0.025	0	0	0	0	0.08	0.02	0
j-->a	WHB	Baleen whales	0	0.005	0	0	0	0	0.05	0.17	0
a-->a	WHB	Baleen whales	0	0.005	0	0	0	0	0.05	0.17	0
j-->j	WHT	Toothed whales	0.006	0.06	0.0015	0.21	0.01	0.15	0.1	0.19	0
a-->j	WHT	Toothed whales	0.006	0.06	0.002	0.21	0.01	0.15	0.1	0.19	0
j-->a	WHT	Toothed whales	0.03	0.025	0.0025	0.0025	0.008	0.5	0.3	0.37	0
a-->a	WHT	Toothed whales	0.03	0.025	0.0025	0.005	0.012	0.5	0.3	0.37	0

Table A15. Consumption parameters (a in Equation 69) in the calibrated model for predation on the rest of the fish groups. Prey groups are listed by column. A value of 0 indicates cases where that predator does not eat that prey. In the left hand column, j-->j signifies juvenile predation on juveniles, a-->j signifies adult predation on juveniles, j-->a signifies juvenile predation on adults, and a-->a signifies adult predation on adults.

PREDATOR			PREY					
Stages	Code	Group	FDE	FDS	FDB	FDC	FDO	FDF
j-->j	FPL	Atlantic mackerel	0.01	0	0.00625	0.0125	0	0
a-->j	FPL	Atlantic mackerel	0.00175	0	0.00625	0.006	0	0
j-->a	FPL	Atlantic mackerel	0	0	3.00E-07	1.00E-08	0	0
a-->a	FPL	Atlantic mackerel	0	0	6.50E-07	1.00E-08	0	0
j-->j	FPS	Atlantic herring	0.00075	0	0.0175	0.0025	0	0
a-->j	FPS	Atlantic herring	0.00075	0	0.0175	0.0025	0	0
j-->a	FPS	Atlantic herring	0	0	1.00E-07	1.00E-08	0	0
a-->a	FPS	Atlantic herring	0	0	1.00E-07	1.00E-08	0	0
j-->j	FVD	White hake	0.13	0.04	0.338	0.078	0.0025	0.18
a-->j	FVD	White hake	0.13	0.04	0.363	0.078	0.0025	0.18
j-->a	FVD	White hake	0.09	0.005	0.378	0.05	0.002	0.57
a-->a	FVD	White hake	0.175	0.008	0.35	0.05	0.18	0.57
j-->j	FVS	Bluefish	0.025	0	0.0151	0.02	0	0
a-->j	FVS	Bluefish	0.03	0	0.0203	0.02	0	0
j-->a	FVS	Bluefish	0.015	0	0.0375	0.01	0	0
a-->a	FVS	Bluefish	0.035	0	0.0243	0.01	0	0
j-->j	FVB	Other piscivores	0.05	0.025	0.08	0.01	0	0.125
a-->j	FVB	Other piscivores	0.05	0.03	0.0925	0.03	0.02	0.125
j-->a	FVB	Other piscivores	0.09	0.001	0.129	0.0075	0	0.8
a-->a	FVB	Other piscivores	0.09	0.002	0.138	0.008	0.08	0.8
j-->j	FVT	Large piscivores	0.061	0	0	0	0	0
a-->j	FVT	Large piscivores	0.061	0	0	0	0	0
j-->a	FVT	Large piscivores	0.0475	0	0	0	0	0
a-->a	FVT	Large piscivores	0.061	0	0	0	0	0
j-->j	FMM	Migratory mesopelagics	0	0	0	0	0	0
a-->j	FMM	Migratory mesopelagics	0	0	0	0	0	0
j-->a	FMM	Migratory mesopelagics	0	0	0	0	0	0
a-->a	FMM	Migratory mesopelagics	0	0	0	0	0	0
j-->j	FBP	Benthopelagics	0	0	0	0	0	0
a-->j	FBP	Benthopelagics	0	0	0	0	0	0
j-->a	FBP	Benthopelagics	0	0	0	0	0	0
a-->a	FBP	Benthopelagics	0	0	0	0	0	0
j-->j	FDD	Goosefish	0.05	0.002	0.0114	0.05	0.001	0.0125
a-->j	FDD	Goosefish	0.05	0.002	0.0114	0.05	0.001	0.0125
j-->a	FDD	Goosefish	0.01	0.002	0.0104	0.02	0.01	0.1
a-->a	FDD	Goosefish	0.03	0.005	0.0105	0.02	0.06	0.1
j-->j	FDE	Shallow demersal fish	0	0	0.0005	0	0	0
a-->j	FDE	Shallow demersal fish	0	0	0.0015	0	0	0
j-->a	FDE	Shallow demersal fish	0	0	0.03	0	0	0
a-->a	FDE	Shallow demersal fish	0	0	0.00875	0	0	0
j-->j	FDS	Atlantic cod	0.075	0.005	0.0655	0.01	0.035	0.03
a-->j	FDS	Atlantic cod	0.075	0.015	0.0655	0.01	0.035	0.03
j-->a	FDS	Atlantic cod	0.1	0.0012	0.157	0.0075	0.03	0.075
a-->a	FDS	Atlantic cod	0.25	0.0045	0.155	0.0075	0.03	0.075
j-->j	FDB	Silver hake	0.07	0.00375	0.106	0.05	0	0.002
a-->j	FDB	Silver hake	0.07	0.00406	0.106	0.08	0	0.002
j-->a	FDB	Silver hake	0.03	0.00225	0.119	0.07	0	0.045
a-->a	FDB	Silver hake	0.0375	0.0035	0.208	0.01	0	0.045

Table A15, continued. Consumption parameters (a in Equation 69) in the calibrated model for predation on the rest of the fish groups. Prey groups are listed by column. A value of 0 indicates cases where that predator does not eat that prey. In the left hand column, j-->j signifies juvenile predation on juveniles, a-->j signifies adult predation on juveniles, j-->a signifies juvenile predation on adults, and a-->a signifies adult predation on adults.

PREDATOR			PREY					
Stages	Code	Group	FDE	FDS	FDB	FDC	FDO	FDF
j-->j	FDC	Miscellaneous demersals	0.03	0.0015	0.00625	0.15	0.005	0.013
a-->j	FDC	Miscellaneous demersals	0.025	0.002	0.00625	0.09	0.005	0.013
j-->a	FDC	Miscellaneous demersals	0.065	0.0007	0.0335	0.08	0.02	0.045
a-->a	FDC	Miscellaneous demersals	0.025	0.000638	0.036	0.02	0.01	0.045
j-->j	FDO	Haddock	0.08	0	0.041	0.018	0	0
a-->j	FDO	Haddock	0.08	0	0.041	0.02	0	0
j-->a	FDO	Haddock	0.004	0	0.143	0.003	0	0
a-->a	FDO	Haddock	0.006	0	0.123	0.003	0	0
j-->j	FDF	Yellowtail flounder	0	0	0.0155	0.0008	0	0
a-->j	FDF	Yellowtail flounder	0	0	0.0165	0.012	0	0
j-->a	FDF	Yellowtail flounder	0	0	0.0875	0.0008	0	0
a-->a	FDF	Yellowtail flounder	0	0	0.055	0.012	0	0
j-->j	SHB	Spiny dogfish	0.004	0.0035	0.128	0.008	0.03	0.075
a-->j	SHB	Spiny dogfish	0.003	0.0035	0.15	0.008	0.03	0.075
j-->a	SHB	Spiny dogfish	0.035	0.0008	0.208	0.003	0.2	0.41
a-->a	SHB	Spiny dogfish	0.035	0.002	0.208	0.003	0.4	0.41
j-->j	SHD	Other demersal sharks	0.55	0	0.335	0.0235	0.015	0.09
a-->j	SHD	Other demersal sharks	0.55	0	0.335	0.0235	0.015	0.08
j-->a	SHD	Other demersal sharks	0.45	0	0.418	0.01	0.17	0.45
a-->a	SHD	Other demersal sharks	0.35	0	0.418	0.01	0.1	0.45
j-->j	SHP	Pelagic sharks	0.575	0.0406	0.324	0	0.1	0
a-->j	SHP	Pelagic sharks	0.575	0.0406	0.324	0	0.1	0
j-->a	SHP	Pelagic sharks	0.375	0.023	0.412	0	0.25	0
a-->a	SHP	Pelagic sharks	0.475	0.08	0.557	0	0.25	0
j-->j	SSK	Skates and rays	0.085	0.001	0.0535	0.05	0.0035	0.05
a-->j	SSK	Skates and rays	0.085	0.002	0.0675	0.015	0.0035	0.05
j-->a	SSK	Skates and rays	0.095	0.009	0.0688	0.005	0.03	0.09
a-->a	SSK	Skates and rays	0.15	0.03	0.112	0.005	0.05	0.09
j-->j	SB	Seabirds	0.475	0.19	0.45	0	0	0
a-->j	SB	Seabirds	0.375	0.2	0.45	0	0	0
j-->a	SB	Seabirds	0.575	0.009	0.513	0	0	0
a-->a	SB	Seabirds	0.675	0.15	0.538	0	0	0
j-->j	PIN	Pinnipeds	0.575	0	0.375	0	0	0
a-->j	PIN	Pinnipeds	0.475	0	0.375	0	0	0
j-->a	PIN	Pinnipeds	0.28	0	0.463	0	0	0
a-->a	PIN	Pinnipeds	0.575	0	0.475	0	0	0
j-->j	REP	Reptiles	0	0	0	0.003	0	0
a-->j	REP	Reptiles	0	0	0	0.003	0	0
j-->a	REP	Reptiles	0	0	0	0.001	0	0
a-->a	REP	Reptiles	0	0	0	0.001	0	0
j-->j	WHB	Baleen whales	0.125	0	0	0	0	0
a-->j	WHB	Baleen whales	0.065	0	0	0	0	0
j-->a	WHB	Baleen whales	0.04	0	0	0	0	0
a-->a	WHB	Baleen whales	0.05	0	0	0	0	0
j-->j	WHT	Toothed whales	0.2	0.02	0.375	0.01	0	0
a-->j	WHT	Toothed whales	0.275	0.02	0.375	0.01	0	0
j-->a	WHT	Toothed whales	0.2	0.03	0.48	0.0045	0	0
a-->a	WHT	Toothed whales	0.275	0.05	0.492	0.0045	0	0

Table A16. Consumption parameters (a in Equation 69) in the calibrated model for predation on the elasmobranch and marine mammal groups. Prey groups are listed by column. A value of 0 indicates cases where that predator does not eat that prey. In the left hand column, j-->j signifies juvenile predation on juveniles, a-->j signifies adult predation on juveniles, j-->a signifies juvenile predation on adults, and a-->a signifies adult predation on adults.

PREDATOR			PREY								
Stages	Code	Group	SHB	SHD	SHP	SSK	SB	PIN	REP	WHB	WHT
j-->j	FPL	Atlantic mackerel	0	0	0	0	0	0	0	0	0
a-->j	FPL	Atlantic mackerel	0	0	0	0	0	0	0	0	0
j-->a	FPL	Atlantic mackerel	0	0	0	0	0	0	0	0	0
a-->a	FPL	Atlantic mackerel	0	0	0	0	0	0	0	0	0
j-->j	FPS	Atlantic herring	0	0	0	0	0	0	0	0	0
a-->j	FPS	Atlantic herring	0	0	0	0	0	0	0	0	0
j-->a	FPS	Atlantic herring	0	0	0	0	0	0	0	0	0
a-->a	FPS	Atlantic herring	0	0	0	0	0	0	0	0	0
j-->j	FVD	White hake	0	0	0	0.005	0	0	0	0	0
a-->j	FVD	White hake	0	0	0	0.005	0	0	0	0	0
j-->a	FVD	White hake	0	0	0	0.00005	0	0	0	0	0
a-->a	FVD	White hake	0	0	0	0.00005	0	0	0	0	0
j-->j	FVS	Bluefish	0.055	0	0	0.001	0	0	0	0	0
a-->j	FVS	Bluefish	0.002	0	0	0.001	0	0	0	0	0
j-->a	FVS	Bluefish	0.0005	0	0	0.001	0	0	0	0	0
a-->a	FVS	Bluefish	0.0005	0	0	0.001	0	0	0	0	0
j-->j	FVB	Other piscivores	0.008	0	0	0	0	0	0	0	0
a-->j	FVB	Other piscivores	0.001	0	0	0.01	0	0	0	0	0
j-->a	FVB	Other piscivores	0.0003	0	0	0	0	0	0	0	0
a-->a	FVB	Other piscivores	0.0003	0	0	0.008	0	0	0	0	0
j-->j	FVT	Large piscivores	0	0	0	0	0	0	0	0	0
a-->j	FVT	Large piscivores	0	0	0	0	0	0	0	0	0
j-->a	FVT	Large piscivores	0	0	0	0	0	0	0	0	0
a-->a	FVT	Large piscivores	0	0	0	0	0	0	0	0	0
j-->j	FMM	Migratory mesopelagics	0	0	0	0	0	0	0	0	0
a-->j	FMM	Migratory mesopelagics	0	0	0	0	0	0	0	0	0
j-->a	FMM	Migratory mesopelagics	0	0	0	0	0	0	0	0	0
a-->a	FMM	Migratory mesopelagics	0	0	0	0	0	0	0	0	0
j-->j	FBP	Benthopelagics	0	0	0	0	0	0	0	0	0
a-->j	FBP	Benthopelagics	0	0	0	0	0	0	0	0	0
j-->a	FBP	Benthopelagics	0	0	0	0	0	0	0	0	0
a-->a	FBP	Benthopelagics	0	0	0	0	0	0	0	0	0
j-->j	FDD	Goosefish	0.0095	0	0	0.0015	0	0	0	0	0

Table A16, continued. Consumption parameters (a in Equation 69) in the calibrated model for predation on the elasmobranch and marine mammal groups. Prey groups are listed by column. A value of 0 indicates cases where that predator does not eat that prey. In the left hand column, j-->j signifies juvenile predation on juveniles, a-->j signifies adult predation on juveniles, j-->a signifies juvenile predation on adults, and a-->a signifies adult predation on adults.

PREDATOR			**PREY**								
Stages	Code	Group	SHB	SHD	SHP	SSK	SB	PIN	REP	WHB	WHT
a-->j	FDD	Goosefish	0.0008	0	0	0.0006	0	0	0	0	0
j-->a	FDD	Goosefish	0.0005	0	0	0.0015	0	0	0	0	0
a-->a	FDD	Goosefish	0.0005	0	0	0.0006	0	0	0	0	0
j-->j	FDE	Shallow demersal fish	0	0	0	0	0	0	0	0	0
a-->j	FDE	Shallow demersal fish	0	0	0	0	0	0	0	0	0
j-->a	FDE	Shallow demersal fish	0	0	0	0	0	0	0	0	0
a-->a	FDE	Shallow demersal fish	0	0	0	0	0	0	0	0	0
j-->j	FDS	Atlantic cod	0.005	0	0	0.011	0	0	0	0	0
a-->j	FDS	Atlantic cod	0	0	0	0.009	0	0	0	0	0
j-->a	FDS	Atlantic cod	0.00115	0	0	0.0008	0	0	0	0	0
a-->a	FDS	Atlantic cod	0	0	0	0.0008	0	0	0	0	0
j-->j	FDB	Silver hake	0	0	0	0	0	0	0	0	0
a-->j	FDB	Silver hake	0	0	0	0	0	0	0	0	0
j-->a	FDB	Silver hake	0	0	0	0	0	0	0	0	0
a-->a	FDB	Silver hake	0	0	0	0	0	0	0	0	0
j-->j	FDC	Miscellaneous demersals	0.0035	0	0	0.01	0	0	0	0	0
a-->j	FDC	Miscellaneous demersals	0.0035	0	0	0.0015	0	0	0	0	0
j-->a	FDC	Miscellaneous demersals	0.00004	0	0	0.00015	0	0	0	0	0
a-->a	FDC	Miscellaneous demersals	0.00004	0	0	0.00015	0	0	0	0	0
j-->j	FDO	Haddock	0	0	0	0	0	0	0	0	0
a-->j	FDO	Haddock	0	0	0	0	0	0	0	0	0
j-->a	FDO	Haddock	0	0	0	0	0	0	0	0	0
a-->a	FDO	Haddock	0	0	0	0	0	0	0	0	0
j-->j	FDF	Yellowtail flounder	0	0	0	0	0	0	0	0	0
a-->j	FDF	Yellowtail flounder	0	0	0	0	0	0	0	0	0
j-->a	FDF	Yellowtail flounder	0	0	0	0	0	0	0	0	0
a-->a	FDF	Yellowtail flounder	0	0	0	0	0	0	0	0	0
j-->j	SHB	Spiny dogfish	0.0005	0	0	0.0075	0	0	0	0	0
a-->j	SHB	Spiny dogfish	0.0005	0	0	0.0075	0	0	0	0	0
j-->a	SHB	Spiny dogfish	0.002	0	0	0.0002	0	0	0	0	0
a-->a	SHB	Spiny dogfish	0.002	0	0	0.0002	0	0	0	0	0
j-->j	SHD	Other demersal sharks	0.0025	0.2	0	0.03	0	0	0.00001	0	0
a-->j	SHD	Other demersal sharks	0.0015	0.21	0	0.03	0	0	0.0001	0	0
j-->a	SHD	Other demersal sharks	0.0002	0.25	0	0.03	0	0	0.00001	0	0

Table A16, continued. Consumption parameters (a in Equation 69) in the calibrated model for predation on the elasmobranch and marine mammal groups. Prey groups are listed by column. A value of 0 indicates cases where that predator does not eat that prey. In the left hand column, j-->j signifies juvenile predation on juveniles, a-->j signifies adult predation on juveniles, j-->a signifies juvenile predation on adults, and a-->a signifies adult predation on adults.

PREDATOR			**PREY**								
Stages	Code	Group	SHB	SHD	SHP	SSK	SB	PIN	REP	WHB	WHT
a-->a	SHD	Other demersal sharks	0.0002	0.275	0	0.03	0	0	0.00001	0	0
j-->j	SHP	Pelagic sharks	0.08	0.51	0.035	0.025	0	0	0.00001	0	0
a-->j	SHP	Pelagic sharks	0.08	0.51	0.035	0.025	0	0	0.00009	0	0
j-->a	SHP	Pelagic sharks	0.05	0.61	0.008	0.01	0	0	0.00001	0	0
a-->a	SHP	Pelagic sharks	0.02	0.61	0.008	0.02	0	0	0.00009	0	0
j-->j	SSK	Skates and rays	0	0	0	0.051	0	0	0	0	0
a-->j	SSK	Skates and rays	0	0	0	0.051	0	0	0	0	0
j-->a	SSK	Skates and rays	0	0	0	0.0015	0	0	0	0	0
a-->a	SSK	Skates and rays	0	0	0	0.0015	0	0	0	0	0
j-->j	SB	Seabirds	0	0	0	0	0	0	0	0	0
a-->j	SB	Seabirds	0	0	0	0	0	0	0	0	0
j-->a	SB	Seabirds	0	0	0	0	0	0	0	0	0
a-->a	SB	Seabirds	0	0	0	0	0	0	0	0	0
j-->j	PIN	Pinnipeds	0	0	0	0	0	0	0	0	0
a-->j	PIN	Pinnipeds	0	0	0	0	0	0	0	0	0
j-->a	PIN	Pinnipeds	0	0	0	0	0	0	0	0	0
a-->a	PIN	Pinnipeds	0	0	0	0	0	0	0	0	0
j-->j	REP	Reptiles	0	0	0	0	0	0	0	0	0
a-->j	REP	Reptiles	0	0	0	0	0	0	0	0	0
j-->a	REP	Reptiles	0	0	0	0	0	0	0	0	0
a-->a	REP	Reptiles	0	0	0	0	0	0	0	0	0
j-->j	WHB	Baleen whales	0	0	0	0	0	0	0	0	0
a-->j	WHB	Baleen whales	0	0	0	0	0	0	0	0	0
j-->a	WHB	Baleen whales	0	0	0	0	0	0	0	0	0
a-->a	WHB	Baleen whales	0	0	0	0	0	0	0	0	0
j-->j	WHT	Toothed whales	0	0.015	0.0015	0.015	0	5.00E-07	0	0.02	0
a-->j	WHT	Toothed whales	0	0.015	0.0015	0.015	0	5.00E-07	0	0.02	0
j-->a	WHT	Toothed whales	0	0.06	0.0045	0.002	0	0.000001	0	0.15	0
a-->a	WHT	Toothed whales	0	0.06	0.0045	0.002	0	0.000001	0	0.15	0

Table A.17. Consumption parameters (a in Equation 69) in the calibrated model for predation on the benthic invertebrate groups. Prey groups are listed by column. A value of 0 indicates cases where that predator does not eat that prey. In the left hand column, j-->j signifies juvenile predation on juveniles, a-->j signifies adult predation on juveniles, j-->a signifies juvenile predation on adults, and a-->a signifies adult predation on adults.

PREDATOR			PREY						
Stages	Code	Group	BFS	BFF	BG	BML	BMS	BD	BC
j-->j	FPL	Atlantic mackerel	0	0.0005	0.00115	0	2.83E-05	0.01	0
a-->j	FPL	Atlantic mackerel	0	0.0005	0.01	0	2.83E-05	0.01	0
j-->a	FPL	Atlantic mackerel	0	0.0005	0.00115	0	2.83E-05	0.01	0
a-->a	FPL	Atlantic mackerel	0	0.0005	0.01	0	2.83E-05	0.01	0
j-->j	FPS	Atlantic herring	0	0.0001	0.0114	0	0.000178	0.01	0
a-->j	FPS	Atlantic herring	0	0.0001	0.0114	0	0.000178	0.1	0
j-->a	FPS	Atlantic herring	0	0.0001	0.0114	0	0.000178	0.01	0
a-->a	FPS	Atlantic herring	0	0.0001	0.0114	0	0.000178	0.1	0
j-->j	FVD	White hake	0.0002	0.000623	0.00006	0.000226	0.007	0.002	0
a-->j	FVD	White hake	0.0002	0.000623	0.00006	0.000226	0.007	0.002	0
j-->a	FVD	White hake	0.0002	0.000623	0.00006	0.000226	0.007	0.002	0
a-->a	FVD	White hake	0.0002	0.000623	0.00006	0.000226	0.007	0.002	0
j-->j	FVS	Bluefish	0	0.000845	0.000262	0	0.002	0.001	0
a-->j	FVS	Bluefish	0	0.000845	0.000262	0	0.002	0.001	0
j-->a	FVS	Bluefish	0	0.000845	0.000262	0	0.002	0.001	0
a-->a	FVS	Bluefish	0	0.000845	0.000262	0	0.002	0.001	0
j-->j	FVB	Other piscivores	0.000003	0.001	0.01	0.00002	0.05	0.04	0
a-->j	FVB	Other piscivores	0.000003	0.001	0.003	0.00002	0.04	0.03	0
j-->a	FVB	Other piscivores	0.000003	0.001	0.01	0.00002	0.05	0.04	0
a-->a	FVB	Other piscivores	0.000003	0.001	0.003	0.00002	0.04	0.03	0
j-->j	FVT	Large piscivores	0	0	0	0	0	0	0
a-->j	FVT	Large piscivores	0	0	0	0	0	0	0
j-->a	FVT	Large piscivores	0	0	0	0	0	0	0
a-->a	FVT	Large piscivores	0	0	0	0	0	0	0
j-->j	FMM	Migratory mesopelagics	0	0	0	0	0.05	0.01	0
a-->j	FMM	Migratory mesopelagics	0	0	0	0	0.05	0.01	0
j-->a	FMM	Migratory mesopelagics	0	0	0	0	0.05	0.01	0
a-->a	FMM	Migratory mesopelagics	0	0	0	0	0.05	0.01	0
j-->j	FBP	Benthopelagics	0	0.015	0.01	0	0.000678	0.05	0
a-->j	FBP	Benthopelagics	0	0.015	0.01	0	0.000678	0.05	0
j-->a	FBP	Benthopelagics	0	0.015	0.01	0	0.000678	0.05	0
a-->a	FBP	Benthopelagics	0	0.015	0.01	0	0.000678	0.05	0
j-->j	FDD	Goosefish	0.0003	0.004	3.82E-05	0.000022	0.000753	0.000646	0
a-->j	FDD	Goosefish	0.0003	0.004	3.82E-05	0.000022	0.000753	0.000646	0
j-->a	FDD	Goosefish	0.0003	0.004	3.82E-05	0.000022	0.000753	0.000646	0
a-->a	FDD	Goosefish	0.0003	0.004	3.82E-05	0.000022	0.000753	0.000646	0
j-->j	FDE	Shallow demersal fish	0	0	0.005	0	0.001	0.08	0
a-->j	FDE	Shallow demersal fish	0	0	0.005	0	0.001	0.08	0
j-->a	FDE	Shallow demersal fish	0	0	0.005	0	0.001	0.08	0
a-->a	FDE	Shallow demersal fish	0	0	0.005	0	0.001	0.08	0
j-->j	FDS	Atlantic cod	0.00005	0.001	0.007	0.0003	0.12	0.08	0
a-->j	FDS	Atlantic cod	0.00005	0.001	0.007	0.0003	0.12	0.08	0
j-->a	FDS	Atlantic cod	0.00005	0.001	0.007	0.0003	0.12	0.08	0
a-->a	FDS	Atlantic cod	0.00005	0.001	0.007	0.0003	0.12	0.08	0
j-->j	FDB	Silver hake	0	0.01	5.85E-05	2.46E-05	0.000176	0.04	0
a-->j	FDB	Silver hake	0	0.000749	5.85E-05	2.46E-05	0.000176	0.02	0
j-->a	FDB	Silver hake	0	0.01	5.85E-05	2.46E-05	0.000176	0.04	0
a-->a	FDB	Silver hake	0	0.000749	5.85E-05	2.46E-05	0.000176	0.02	0

Table A17, continued. Consumption parameters (a in Equation 69) in the calibrated model for predation on the benthic invertebrate groups. Prey groups are listed by column. A value of 0 indicates cases where that predator does not eat that prey. In the left hand column, j-->j signifies juvenile predation on juveniles, a-->j signifies adult predation on juveniles, j-->a signifies juvenile predation on adults, and a-->a signifies adult predation on adults.

PREDATOR			PREY						
Stages	Code	Group	BFS	BFF	BG	BML	BMS	BD	BC
j-->j	FDC	Miscellaneous demersals	0.00003	0.01	0.008	0.00003	0.08	0.07	0
a-->j	FDC	Miscellaneous demersals	0.00003	0.0105	0.008	0.00003	0.09	0.08	0
j-->a	FDC	Miscellaneous demersals	0.00003	0.01	0.008	0.00003	0.08	0.07	0
a-->a	FDC	Miscellaneous demersals	0.00003	0.0105	0.008	0.00003	0.09	0.08	0
j-->j	FDO	Haddock	0.0001	0.0005	0.0007	0.0001	0.355	0.08	0
a-->j	FDO	Haddock	0.0001	0.0005	0.0007	0.0001	0.332	0.07	0
j-->a	FDO	Haddock	0.0001	0.0005	0.0007	0.0001	0.355	0.08	0
a-->a	FDO	Haddock	0.0001	0.0005	0.0007	0.0001	0.332	0.07	0
j-->j	FDF	Yellowtail flounder	0.0001	0.008	0.009	0	0.0119	0.08	0
a-->j	FDF	Yellowtail flounder	0.0001	0.008	0.009	0	0.0119	0.08	0
j-->a	FDF	Yellowtail flounder	0.0001	0.008	0.009	0	0.0119	0.08	0
a-->a	FDF	Yellowtail flounder	0.00001	0.008	0.009	0	0.0119	0.08	0
j-->j	SHB	Spiny dogfish	0.000005	0.001	0.0008	0.00005	0.0242	0.005	0
a-->j	SHB	Spiny dogfish	0.000005	0.001	0.0008	0.00005	0.002	0.002	0
j-->a	SHB	Spiny dogfish	0.000005	0.001	0.0008	0.00005	0.0242	0.005	0
a-->a	SHB	Spiny dogfish	0.000005	0.001	0.0008	0.00005	0.002	0.002	0
j-->j	SHD	Other demersal sharks	0.0001	0.001	0.007	0.0003	0.3	0.008	0
a-->j	SHD	Other demersal sharks	0.0001	0.001	0.007	0.0003	0.3	0.008	0
j-->a	SHD	Other demersal sharks	0.0001	0.001	0.007	0.0003	0.35	0.008	0
a-->a	SHD	Other demersal sharks	0.0001	0.001	0.007	0.0003	0.35	0.008	0
j-->j	SHP	Pelagic sharks	0	0	0	0	0	0	0
a-->j	SHP	Pelagic sharks	0	0	0	0	0	0	0
j-->a	SHP	Pelagic sharks	0	0	0	0	0	0	0
a-->a	SHP	Pelagic sharks	0	0	0	0	0	0	0
j-->j	SSK	Skates and rays	0.000075	0.025	0.001	0.003	0.167	0.08	0
a-->j	SSK	Skates and rays	0.000075	0.025	0.001	0.003	0.167	0.08	0
j-->a	SSK	Skates and rays	0.000075	0.025	0.001	0.003	0.167	0.08	0
a-->a	SSK	Skates and rays	0.000075	0.025	0.001	0.003	0.167	0.08	0
j-->j	SB	Seabirds	0	0	0	0.0025	0.00575	0	0
a-->j	SB	Seabirds	0	0	0	0.0025	0.00575	0	0
j-->a	SB	Seabirds	0	0	0	0.0025	0.00575	0	0
a-->a	SB	Seabirds	0	0	0	0.0025	0.00575	0	0
j-->j	PIN	Pinnipeds	0	0.01	0.001	0.00115	0.00115	0	0
a-->j	PIN	Pinnipeds	0	0.01	0.001	0.00115	0.00115	0	0
j-->a	PIN	Pinnipeds	0	0.01	0.001	0.00115	0.00115	0	0
a-->a	PIN	Pinnipeds	0	0.01	0.001	0.00115	0.00115	0	0
j-->j	REP	Reptiles	0	0.0575	0.01	0.0275	0.1	0	0
a-->j	REP	Reptiles	0	0.0575	0.01	0.0275	0.1	0	0
j-->a	REP	Reptiles	0	0.0575	0.01	0.0275	0.1	0	0
a-->a	REP	Reptiles	0	0.0575	0.01	0.0275	0.1	0	0
j-->j	WHB	Baleen whales	0	0	0	0	0	0	0
a-->j	WHB	Baleen whales	0	0	0	0	0	0	0
j-->a	WHB	Baleen whales	0	0	0	0	0	0	0
a-->a	WHB	Baleen whales	0	0	0	0	0	0	0
j-->j	WHT	Toothed whales	0	0	0	0	0.01	0	0
a-->j	WHT	Toothed whales	0	0	0	0	0.01	0	0
j-->a	WHT	Toothed whales	0	0	0	0	0.01	0	0
a-->a	WHT	Toothed whales	0	0	0	0	0.01	0	0

Table A18. Consumption parameters (a in Equation 69) in the calibrated model for predation on the plankton, shrimp and squid groups. Prey groups are listed by column. A value of 0 indicates cases where that predator does not eat that prey. In the left hand column, j-->j signifies juvenile predation on juveniles, a-->j signifies adult predation on juveniles, j-->a signifies juvenile predation on adults, and a --> a signifies adult predation on adults.

PREDATOR			PREY						
Stages	Code	Group	CEP	PWN	ZL	ZG	ZM	ZS	DC
j-->j	FPL	Atlantic mackerel	0	0.008	0.003	0.00175	0.0025	0.03	0
a-->j	FPL	Atlantic mackerel	0.00001	0.008	0.003	0.00175	0.0025	0.03	0
j-->a	FPL	Atlantic mackerel	0	0.008	0.003	0.00175	0.0025	0.01	0
a-->a	FPL	Atlantic mackerel	0.00001	0.008	0.003	0.00175	0.0025	0.01	0
j-->j	FPS	Atlantic herring	0	0.0025	0.02	0.0075	0.02	0	0
a-->j	FPS	Atlantic herring	0	0.0025	0.015	0.0075	0.02	0	0
j-->a	FPS	Atlantic herring	0	0.0025	0.02	0.0075	0.02	0	0
a-->a	FPS	Atlantic herring	0	0.0025	0.015	0.0075	0.02	0	0
j-->j	FVD	White hake	0.02	0.14	0.175	0.000126	1.88E-05	0	0
a-->j	FVD	White hake	0.02	0.14	0.175	0.000126	1.88E-05	0	0
j-->a	FVD	White hake	0.01	0.1	0.175	0.000126	1.88E-05	0	0
a-->a	FVD	White hake	0.01	0.1	0.175	0.000126	1.88E-05	0	0
j-->j	FVS	Bluefish	0.003	0.052	0.1	0.001	0	0	0
a-->j	FVS	Bluefish	0.003	0.052	0.1	0.001	0	0	0
j-->a	FVS	Bluefish	0.002	0.07	0.1	0.001	0	0	0
a-->a	FVS	Bluefish	0.002	0.07	0.1	0.001	0	0	0
j-->j	FVB	Other piscivores	0.001	0.21	0.03	0.015	0.000726	0	0
a-->j	FVB	Other piscivores	0.001	0.21	0.03	0.015	0.000726	0	0
j-->a	FVB	Other piscivores	0.001	0.31	0.03	0.015	0.000726	0	0
a-->a	FVB	Other piscivores	0.001	0.31	0.03	0.015	0.000726	0	0
j-->j	FVT	Large piscivores	0.01	0	0.06	0.00025	0	0	0
a-->j	FVT	Large piscivores	0.01	0	0.06	0.00025	0	0	0
j-->a	FVT	Large piscivores	0.01	0	0.06	0.00025	0	0	0
a-->a	FVT	Large piscivores	0.01	0	0.06	0.00025	0	0	0
j-->j	FMM	Migratory mesopelagics	0	0	0.3	0	0.015	0	0
a-->j	FMM	Migratory mesopelagics	0	0	0.3	0	0.015	0	0
j-->a	FMM	Migratory mesopelagics	0	0	0.3	0	0.015	0	0
a-->a	FMM	Migratory mesopelagics	0	0	0.3	0	0.015	0	0
j-->j	FBP	Benthopelagics	0.01	0.25	0.27	0.01	0.06	0	0
a-->j	FBP	Benthopelagics	0.01	0.25	0.27	0.01	0.06	0	0
j-->a	FBP	Benthopelagics	0.011	0.2	0.27	0.01	0.06	0	0
a-->a	FBP	Benthopelagics	0.011	0.2	0.27	0.01	0.06	0	0
j-->j	FDD	Goosefish	0.02	0.08	0.01	0	0	0	0
a-->j	FDD	Goosefish	0.03	0.08	0.01	0	0	0	0
j-->a	FDD	Goosefish	0.012	0.06	0.01	0	0	0	0
a-->a	FDD	Goosefish	0.012	0.06	0.01	0	0	0	0
j-->j	FDE	Shallow demersal fish	0	0.062	0.18	0.0125	0.004	0	0
a-->j	FDE	Shallow demersal fish	0	0.062	0.18	0.0125	0.004	0	0
j-->a	FDE	Shallow demersal fish	0	0.062	0.18	0.0125	0.004	0	0
a-->a	FDE	Shallow demersal fish	0	0.062	0.18	0.0125	0.004	0	0
j-->j	FDS	Atlantic cod	0.01	0.06	0.035	0.002	0.000144	0	0
a-->j	FDS	Atlantic cod	0.01	0.06	0.035	0.002	0.000144	0	0
j-->a	FDS	Atlantic cod	0.005	0.1	0.035	0.002	0.000144	0	0
a-->a	FDS	Atlantic cod	0.005	0.1	0.035	0.002	0.000144	0	0
j-->j	FDB	Silver hake	0.009	0.15	0.06	0.0017	0.01	0	0
a-->j	FDB	Silver hake	0.009	0.15	0.02	0.0017	0.0001	0	0
j-->a	FDB	Silver hake	0.007	0.18	0.06	0.0017	0.01	0	0
a-->a	FDB	Silver hake	0.015	0.18	0.02	0.0017	0.0001	0	0
j-->j	FDC	Miscellaneous demersals	0.0005	0.0494	0.019	0.00225	0.000722	0	0

Table A18, continued. Consumption parameters (a in Equation 69) in the calibrated model for predation on the plankton, shrimp and squid groups. Prey groups are listed by column. A value of 0 indicates cases where that predator does not eat that prey. In the left hand column, j-->j signifies juvenile predation on juveniles, a-->j signifies adult predation on juveniles, j-->a signifies juvenile predation on adults, and a --> a signifies adult predation on adults.

PREDATOR			PREY						
Stages	Code	Group	CEP	PWN	ZL	ZG	ZM	ZS	DC
a-->j	FDC	Miscellaneous demersals	0.0005	0.0494	0.019	0.00225	0.000722	0	0
j-->a	FDC	Miscellaneous demersals	0.0004	0.0297	0.019	0.00225	0.000722	0	0
a-->a	FDC	Miscellaneous demersals	0.0004	0.0297	0.019	0.00225	0.000722	0	0
j-->j	FDO	Haddock	0.0125	0.08	0.02	0.018	0.000566	0	0
a-->j	FDO	Haddock	0.0125	0.1	0.02	0.018	0.000566	0	0
j-->a	FDO	Haddock	0.018	0.15	0.02	0.018	0.000566	0	0
a-->a	FDO	Haddock	0.018	0.15	0.02	0.018	0.000566	0	0
j-->j	FDF	Yellowtail flounder	0	0.08	0.15	0.002	0.00161	0	0
a-->j	FDF	Yellowtail flounder	0	0.08	0.15	0.002	0.00161	0	0
j-->a	FDF	Yellowtail flounder	0	0.1	0.15	0.002	0.00161	0	0
a-->a	FDF	Yellowtail flounder	0	0.1	0.15	0.002	0.00161	0	0
j-->j	SHB	Spiny dogfish	0.0005	0.43	0.0016	0.0005	3.32E-05	0	0
a-->j	SHB	Spiny dogfish	0.0005	0.43	0.002	0.0005	0.00001	0	0
j-->a	SHB	Spiny dogfish	0.0003	0.35	0.0016	0.0005	3.32E-05	0	0
a-->a	SHB	Spiny dogfish	0.0003	0.35	0.003	0.0005	0.00001	0	0
j-->j	SHD	Other demersal sharks	0.01	0.5	0.05	0.00002	1.06E-05	0	0
a-->j	SHD	Other demersal sharks	0.07	0.45	0.05	0.00002	1.06E-05	0	0
j-->a	SHD	Other demersal sharks	0.05	0.4	0.05	0.00002	1.06E-05	0	0
a-->a	SHD	Other demersal sharks	0.05	0.4	0.05	0.00002	1.06E-05	0	0
j-->j	SHP	Pelagic sharks	0.08	0	0.058	0	0	0	0.115
a-->j	SHP	Pelagic sharks	0.08	0	0.0075	0	0	0	0.1
j-->a	SHP	Pelagic sharks	0.1	0	0.058	0	0	0	0.115
a-->a	SHP	Pelagic sharks	0.1	0	0.0075	0	0	0	0.1
j-->j	SSK	Skates and rays	0.007	0.18	0.00812	0.005	0.000597	0	0
a-->j	SSK	Skates and rays	0.007	0.18	0.00812	0.005	0.000597	0	0
j-->a	SSK	Skates and rays	0.01	0.2	0.00812	0.005	0.000597	0	0
a-->a	SSK	Skates and rays	0.01	0.2	0.00812	0.005	0.000597	0	0
j-->j	SB	Seabirds	0.05	0.78	0.155	0.005	0.00575	0	0.23
a-->j	SB	Seabirds	0.05	0.78	0.155	0.005	0.00575	0	0.23
j-->a	SB	Seabirds	0.03	0.8	0.155	0.005	0.00575	0	0.23
a-->a	SB	Seabirds	0.03	0.8	0.155	0.005	0.00575	0	0.23
j-->j	PIN	Pinnipeds	0.125	0.8	0	0	0	0	0.0575
a-->j	PIN	Pinnipeds	0.125	0.8	0	0	0	0	0.0575
j-->a	PIN	Pinnipeds	0.075	0.8	0	0	0	0	0.0575
a-->a	PIN	Pinnipeds	0.075	0.8	0	0	0	0	0.0575
j-->j	REP	Reptiles	0	0.8	0.05	0.25	0	0	0.23
a-->j	REP	Reptiles	0	0.8	0.05	0.25	0	0	0.23
j-->a	REP	Reptiles	0	0.8	0.05	0.25	0	0	0.23
a-->a	REP	Reptiles	0	0.8	0.05	0.25	0	0	0.23
j-->j	WHB	Baleen whales	0.0015	0.09	0.004	0	0.003	0	0
a-->j	WHB	Baleen whales	0.0015	0.09	0.004	0	0.003	0	0
j-->a	WHB	Baleen whales	0.003	0.15	0.004	0	0.003	0	0
a-->a	WHB	Baleen whales	0.003	0.15	0.004	0	0.003	0	0
j-->j	WHT	Toothed whales	0.03	0	0	0	0	0	0.115
a-->j	WHT	Toothed whales	0.03	0	0	0	0	0	0.115
j-->a	WHT	Toothed whales	0.03	0	0	0	0	0	0.115
a-->a	WHT	Toothed whales	0.03	0	0	0	0	0	0.115

Table A19. Clearance rates (mg^3 N / day) for each vertebrate group in Atlantis NEUS for each age class.

CODE	GROUP	AGE CLASS									
		1	2	3	4	5	6	7	8	9	10
FPL	Atlantic mackerel	0.01	0.05	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
FPS	Atlantic herring	0.15	0.4	12	15	15	17	17	17	17	17
FVD	White hake	30	150	400	600	600	600	600	650	650	950
FVS	Bluefish	30	60	105	180	250	250	815	815	815	815
FVT	Large piscivores	380	17000	28500	43000	44000	44000	44000	44000	44000	44000
FVB	Other piscivores	1	1.8	5	10.5	25.5	25.5	25.5	25.5	25.5	28
FMM	Migratory mesopelagics	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
FBP	Benthopelagics	5.3	10.6	16.6	25.7	25.7	25.8	25.8	25.8	25.8	25.8
FDD	Goosefish	600	800	900	1600	1800	1900	2100	2200	2200	2200
FDS	Atlantic cod	50	250	850	1500	1800	2100	2100	2500	2600	2600
FDB	Silver hake	5	130	160	150	150	180	125	128	130	130
FDC	Miscellaneous demersals	1	5	15	25	45	45	45	45	50	50
FDO	Haddock	5	15	25	70	105	105	105	105	150	150
FDE	Shallow demersal fish	2.5	7.5	12	20.8	28.8	28.8	30.8	30.8	35	35
FDF	Yellowtail flounder	2.5	7.5	15	17.8	18.8	19.8	20.8	21.8	22	22
SHD	Other demersal sharks	5	20	40	50	50	70	70	70	100	100
SHP	Pelagic sharks	30	150	350	850	1450	1450	1850	1850	1850	1850
SHB	Spiny dogfish	5	7.5	20	45	50	80	130	180	210	210
SSK	Skates and rays	900	1080	1020	1040	1060	1070	1075	1080	2110	4210
SB	Seabirds	8000	8000	8000	5000	5000	5000	4500	4000	3500	3000
REP	Reptiles	10	12	25	25	25	45	48	48	48	48
PIN	Pinnipeds	25	1400	1400	1400	1200	1200	1000	1000	1000	1000
WHB	Baleen whales	50000000	15000000	15000000	15000000	15000000	15000000	15000000	15000000	15000000	15000000
WHT	Toothed whales	6000	5000	5000	5000	8000	8000	8000	8000	8000	8000

Table A20. Clearance rates for each invertebrate group in Atlantis NEUS.

CODE	GROUP	C (mg^3 N / day)
ZG	Gelatinous zooplankton	0.003
ZL	Carnivorous zooplankton	0.02
ZM	Copepods	0.008
ZS	Microzooplankton	0.15
DF	Dinoflagellates	0.01
BFS	Sea scallop	0.02
BFF	Other benthic filter feeder	0.00002
BD	Deposit feeder	0.0005
BC	Benthic carnivore	0.0006
BG	Benthic grazer	0.000075
BMS	Shallow macrozoobenthos	0.00005
BML	Lobster	0.000065
BO	Meiobenthos	0.001
CEP	Squid	0.01455
jCEP	Juv. Squid	0.01455
PWN	Shrimp	0.0015
jPWN	Juv. Shrimp	0.0015

Table A21. q (catchability) parameters for each gear on each functional group for the dynamic effort run of Atlantis NEUS.

		GEAR									GEAR		
CODE	GROUP	midwcCEP	midwcFP	dredgeBFS	netFD	plineFVO	pseineFVO	midwcFD	dlineFD	recfish	ptrawlPWN	dtrawlFBP	trapFDE
FPL	Atlantic mackerel	0	0.07	0	0	0	0	0.3	0	0	0	0	0
FPS	Atlantic herring	0	0.3	0	0	0	0	0.4	0	0	0	0	0
FVD	White hake	0	0	0	0.1	0.0001	0	0	0.5	1.00E-07	0.006	0	0.001
FVS	Bluefish	0	0	0	0.1	0	0	0	0	1.00E-07	0	0.3	0.00008
FVT	Large piscivores	0	0	0	0	0.9	0.9	0	0.04	8.00E-09	0	0	0
FVB	Other piscivores	0	0	0	0.1	0	0	0	0.00002	5.00E-12	0.00001	0	0
FMM	Migratory mesopelagics	0	0.04	0	0	0	0	0.04	0	0	0	0	0
FBP	Benthopelagics	0	0.05	0	0.005	0	0	0	0	5.00E-10	0.08	0.000006	0
FDD	Goosefish	0	0	0.001	0.002	0	0	0	0	0	0	0	0.6
FDS	Atlantic cod	0	0	0	0.002	0	0	0	0.02	2.00E-09	0	0	0.00002
FDB	Silver hake	0	0.05	0	0	0	0	0.6	0	0	0	0.000001	0.0001
FDC	Miscellaneous demersals	0	0	0.6	0.003	0	0	0	0.0001	1.00E-09	0.0002	1.00E-07	0
FDO	Haddock	0	0	0	0.00002	0	0	0	0.005	0	0.0005	0	0.005
FDE	Shallow demersal fish	0.9	0.1	0	0	0	0	0.000002	0	0.00002	0	0.9	0
FDF	Yellowtail flounder	0	0	0.0001	0.0002	0	0	0	0	0	0.002	0	0.0005
SHB	Spiny dogfish	0	0.0006	0	0.0006	0	0	0	0.00001	0	0	0.005	0
SHD	Other demersal sharks	0	0	0	0.00003	0.5	0.000003	0.0002	0.00003	3.00E-09	0	0.0006	0
SHP	Pelagic sharks	0	0	0	0	0.0001	0	0	0.000001	1.00E-07	0	1.00E-07	0
SSK	Skates and rays	0	0	0	0.001	0	0	0	0.002	4.00E-07	0.00001	0.04	0
SB	Seabirds	0	0	0	0.000001	0.1	0	0	0.000001	0	0	0.000001	0
PIN	Pinnipeds	0	0	0	0.01	0	0	0	0	0	0.0000001	0.001	0.000001
REP	Reptiles	0	0	0	0.01	0.05	0	0	0.000001	0	0.0000001	0.000001	0.000001
WHB	Baleen whales	0	0	0	0	0	0	0	0	0	0	0	0
WHT	Toothed whales	0	0	0	0.05	0.01	0	0	0.0001	0	0	0.01	0.0001
CEP	Squid	0.9	0	0.9	0	0	0	0	0	0.00002	0.9	0	0
BFS	Sea scallop	0	0	0.9	0	0	0	0	0	0	0.0005	0	0.0005
BG	Benthic grazer	0	0	0.25	0	0	0	0	0	0	0.0005	0	0.1
BMS	Shallow macrozoobenthos	0	0	0.000005	0	0	0	0	0	0	0.005	0	0.0001
BML	Lobster	0	0	0	0	0	0	0	0	0	0	0	0
BD	Deposit feeder	0	0	0.0015	0	0	0	0	0	0	0.00001	0	0.001
PWN	Shrimp	0	0	0	0.9	0	0	0	0	0	0.9	0	0
BFF	Other benthic filter feeder	0	0	0.25	0	0	0	0	0	0	0.0005	0	0.0001
ZL	Carnivorous zooplankton	0	0.001	0.01	0	0	0	0.001	0	0	0.02	0	0

Table A21, continued. q (catchability) parameters for each gear on each functional group for the dynamic effort run of Atlantis NEUS.

					GEAR								
CODE	**GROUP**	pseineFP	trapBMS	dtrawlCEP	dtrawlFD	dtrawlFDB	dtrawlFDO	midwcFD	dlineFD	recfish	ptrawlPWN (**GEAR**)	dtrawlFBP	trapFDE
FPL	Atlantic mack	0.01	0	0	0.008	0	0	0.3	0	0	0	0	0
FPS	Atlantic herrin	0.3	0	0	0	0	0	0.4	0	0	0	0	0
FVD	White hake	0	0	0.00008	0.2	0.04	0	0	0.5	1.00E-07	0.006	0	0.001
FVS	Bluefish	0.8	0	0	0.01	0.02	0.5	0	0	1.00E-07	0	0.3	0.00008
FVT	Large piscivo	0	0	0	0	0	0	0	0.04	8.00E-09	0	0	0
FVB	Other piscivo	0	0.004	0.001	0.2	0.0003	0	0	0.00002	5.00E-12	0.00001	0	0
FMM	Migratory me	0.04	0	0.04	0	0	0	0.04	0	0	0	0	0
FBP	Benthopelagi	0.005	0.0005	0.002	0.04	0.3	0	0	0	5.00E-10	0.08	0.000006	0
FDD	Goosefish	0	0	0	0	0	0	0	0	0	0	0	0.6
FDS	Atlantic cod	0	0	0.00002	0.01	0.9	0.4	0	0.02	2.00E-09	0	0	0.00002
FDB	Silver hake	0	0	0.00005	0.08	0.2	0.6	0.6	0	0	0	0.000001	0.0001
FDC	Miscellaneou	0	0	0.00001	0.04	0.002	0.002	0	0.0001	1.00E-09	0.0002	1.00E-07	0
FDO	Haddock	0	0	0	0.05	0.1	0	0	0.005	0	0.0005	0	0.005
FDE	Shallow deme	0.99	0	0	0	0	0	0.000002	0	0.00002	0	0.9	0
FDF	Yellowtail flou	0	0.0001	0.0001	0.1	0.001	0	0	0	0	0.002	0	0.0005
SHB	Spiny dogfish	0	0	0.00001	0	0.8	0.00001	0	0.00001	0	0	0.005	0
SHD	Other demers	0	0	0	0.0006	0.06	2.00E-07	0.0002	0.00003	3.00E-09	0	0.0006	0
SHP	Pelagic shark	0.00003	0	0	0	0	0	0	0.000001	1.00E-07	0	1.00E-07	0
SSK	Skates and ra	0	0	0.004	0.002	0.4	0	0	0.002	4.00E-07	0.00001	0.04	0
SB	Seabirds	0	0	0	0	0	0	0	0.000001	0	0	0.000001	0
PIN	Pinnipeds	0	0	0.000001	0.000001	0.000001	0	0	0	0	0.0000001	0.001	0.000001
REP	Reptiles	0	0	0.000001	0.000001	0.000001	0	0	0.000001	0	0.0000001	0.000001	0.000001
WHB	Baleen whale	0	0.001	0	0	0	0	0	0	0	0	0	0
WHT	Toothed whal	0	0	0	0.0001	0.0001	0	0	0.0001	0	0	0.01	0.0001
CEP	Squid	0	0	0.9	0	0	0	0	0	0.00002	0.9	0	0
BFS	Sea scallop	0	0	0.0003	0.0001	0.005	0	0	0	0	0.0005	0	0.0005
BG	Benthic graze	0	0.001	0.1	0.05	0.1	0	0	0	0	0.0005	0	0.1
BMS	Shallow macr	0	0	0	0.001	0.02	0	0	0	0	0.005	0	0.0001
BML	Lobster	0	0.01	0	0.01	0	0	0	0	0	0	0	0
BD	Deposit feede	0	0.0001	0.001	0.001	0.001	0	0	0	0	0.00001	0	0.001
PWN	Shrimp	0	0	0	0	0	0	0	0	0	0.9	0	0
BFF	Other benthic	0	0	0.01	0.01	0.01	0	0	0	0	0.0005	0	0.0001
ZL	Carnivorous z	0	0	0	0	0	0	0.001	0	0	0.02	0	0

Table A22. Effort (in days per day) for each region for the fixed effort run of Atlantis NEUS. Boxes 0 and 23-29 were boundary boxes which had no effort assigned, and are not included in the below table.

FISHERY	REGION											
	1	2	3	4	5	6	7	8	9	10	11	12
midwcCEP	0.07	0.1	0.1	0.05	0.07	0.1	0.05	0.08	0.1	0.07	0	0.07
midwcFP	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
dredgeBFS	0	0.15	0.05	0	0	0.15	0	0.1	0.15	0	0	0.07
netFD	0	0	0	0	0	0	0	0.2	0	0.2	0.1	0.1
plineFVO	0	0	0.2	0	0.1	0.2	0	0.05	0.2	0	0	0
pseineFVO	0	0	0.2	0	0	0.25	0	0	0.3	0	0	0
pseineFP	0	0	0	0	0	0	0	0.2	0.2	0	0.2	0.1
trapBMS	0.01	0.01	0.01	0.01	0.01	0.01	0.08	0.01	0.01	0.15	0.15	0.01
dtrawlCEP	0.07	0.07	0.07	0.07	0.07	0.07	0.1	0.1	0.1	0.07	0	0.07
dtrawlFD	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
dtrawlFDO	0	0	0	0	0	0	0	0.3	0	0.3	0	0
dtrawlFDB	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
midwcFD	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
dlineFD	0	0	0	0	0	0	0	0.13	0	0.14	0.14	0.14
REC	0.11	0.05	0.01	0.11	0.04	0.05	0.11	0.05	0.025	0.11	0.01	0.01
ptrawlPWN	0	0	0	0	0	0	0	0	0	0	0.2	0.1
dtrawlFBP	0.15	0	0	0.1	0	0	0.15	0	0	0.2	0	0
trapFDE	0	0.05	0.05	0.05	0.05	0.05	0.05	0	0.1	0	0.05	0.05

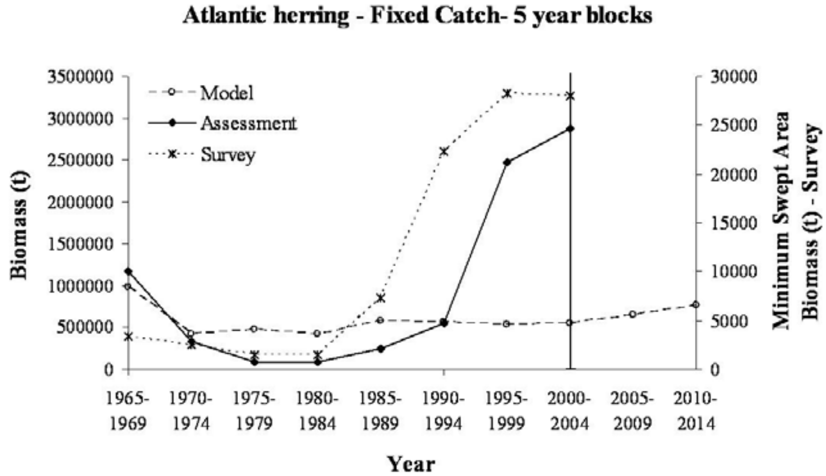
Table A22, continued. Effort (in days per day) for each region for the fixed effort run of Atlantis NEUS. Boxes 0 and 23-29 were boundary boxes which had no effort assigned, and are not included in the below table.

FISHERY	REGION									
	13	14	15	16	17	18	19	20	21	22
midwcCEP	0.07	0.07	0	0	0	0	0	0	0	0
midwcFP	0.055	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
dredgeBFS	0.2	0.03	0.1	0	0	0	0	0	0	0
netFD	0	0	0	0	0.2	0.2	0	0	0	0
plineFVO	0	0.2	0.05	0	0	0	0	0	0	0
pseineFVO	0	0.25	0	0	0	0	0	0	0	0
pseineFP	0.15	0.15	0	0	0	0	0	0	0	0
trapBMS	0.01	0.01	0.01	0.15	0.15	0.09	0.08	0.01	0.01	0.01
dtrawlCEP	0.07	0.07	0	0	0	0	0	0	0	0
dtrawlFD	0.055	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
dtrawlFDO	0	0	0	0	0.2	0.2	0	0	0	0
dtrawlFDB	0.055	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
midwcFD	0.055	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
dlineFD	0.01	0.01	0.02	0.09	0.02	0.02	0.09	0.09	0.05	0.05
REC	0.01	0.025	0.01	0.01	0.11	0.11	0.01	0.01	0.01	0.01
ptrawlPWN	0	0	0	0.2	0	0	0.2	0.2	0.1	0
dtrawlFBP	0	0	0	0	0.2	0.2	0	0	0	0
trapFDE	0.05	0.1	0.1	0.05	0.05	0	0	0.1	0.05	0

Table A23. Effort parameters for each fishery for the dynamic effort run of Atlantis NEUS. If the CPUE was below the minimum threshold or above the maximum threshold, then effort was changed by the proportional change in effort (a decrease of 1 - proportional change, or an increase of 1 + proportional change respectively). Maximum effort per day is a constraint on effort allowed for the fishery.

CODE	FISHERY	Minimum Threshold CPUE (kg / d)	Maximum Threshold CPUE (kg / d)	Proportional Change in Effort	Maximum Effort per day
dlineFD	Line fishery on demersals	200	340	0.4	75
dredgeBFS	Scallop dredge	1500	5400	0.2	0.298
dtrawlCEP	Demersal trawl on cephalopods	1000	2800	0.3	5.72
dtrawlFBP	Demersal trawl on benthopelagics	1000	20000	0.6	2
dtrawlFD	Demersal trawl on other deep demersals	1650	2450	0.1	250
dtrawlFDB	Demersal trawl on shallow demersals	100	14000	0.9	2
dtrawlFDO	Demersal trawl on cod and haddock	40	600	0.3	60
midwcCEP	Midwater trawl on cephalopods	50	560000	0.65	0.22
midwcFD	Midwater Trawl - international fleet	1000	6800	0.2	20
midwcFP	Midwater trawl on small pelagics	2500	75000	0.55	1
netFD	Demersal gillnet on other deep demersals	40	250	0.25	5.5
plineFVO	Pelagic line on tuna and sharks	25	190	0.9	15
pseineFP	Purse seine on small pelagics	120	880	0.5	0.5
pseineFVO	Purse seine on tuna and sharks	1E-18	1E-13	0.7	100
ptrawlPWN	Shrimp trawl	10	1300	0.1	20
REC	Recreational fishery	0	0	1	107801
trapBMS	Lobster traps	1	10	0.4	181.74
trapFDE	Trap on demersals	30	440	0.3	0.07

APPENDIX B: Atlantis NEUS – BIOMASS TRAJECTORY RESULTS



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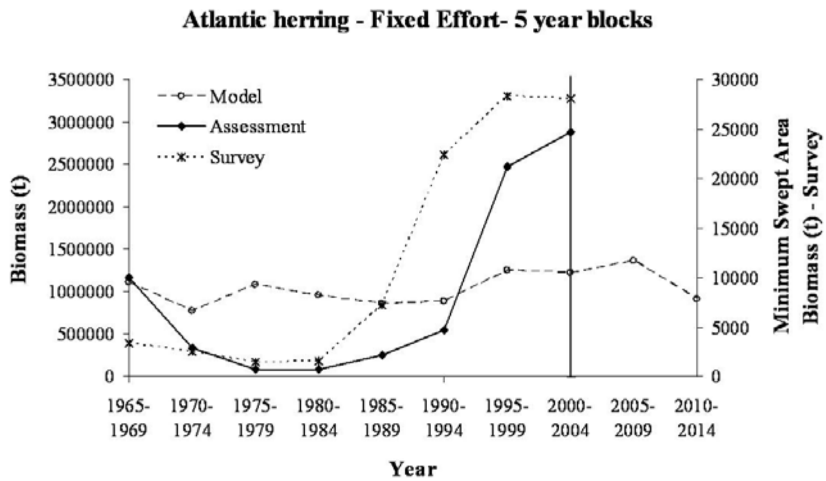
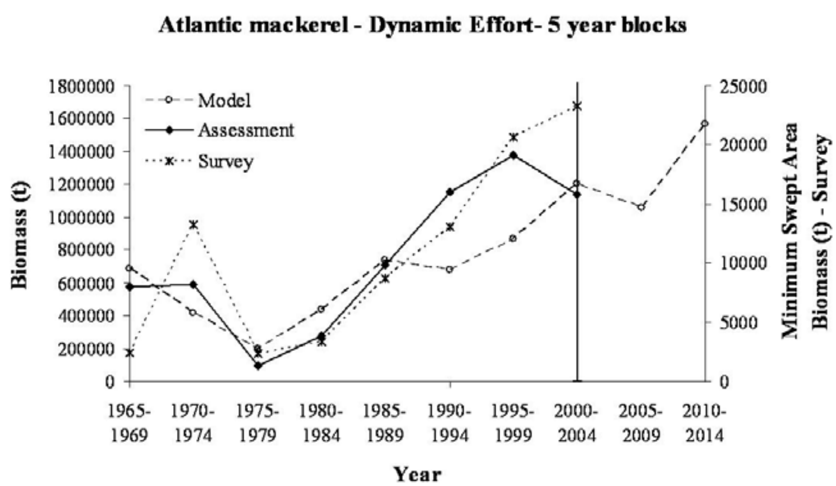
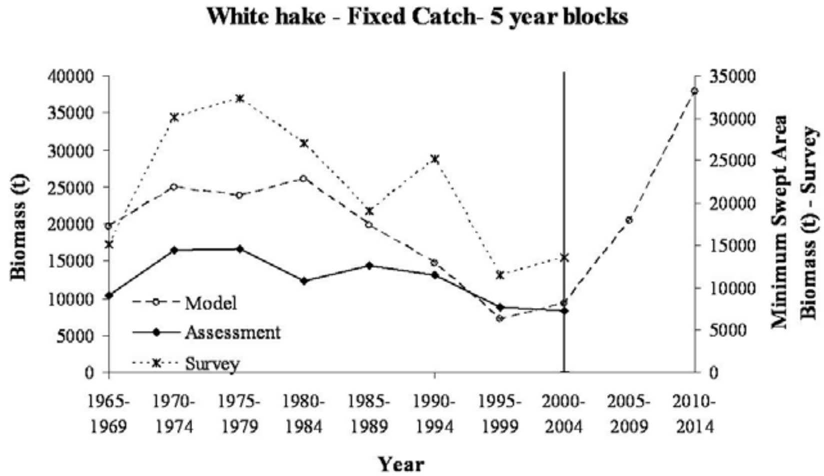


b.



c.

Figure B1. Atlantic herring (*Clupea harengus*) biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



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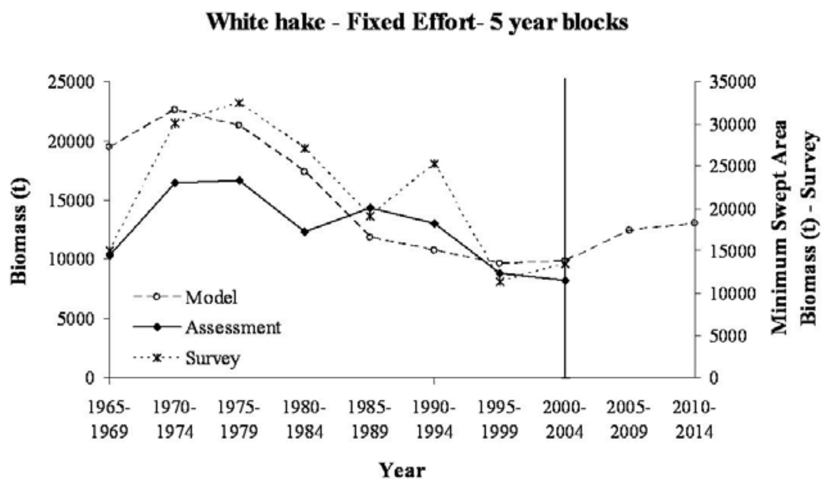
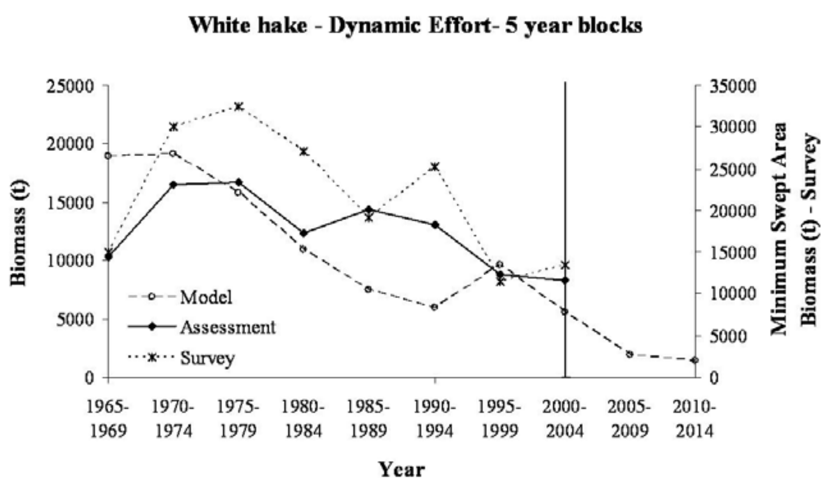
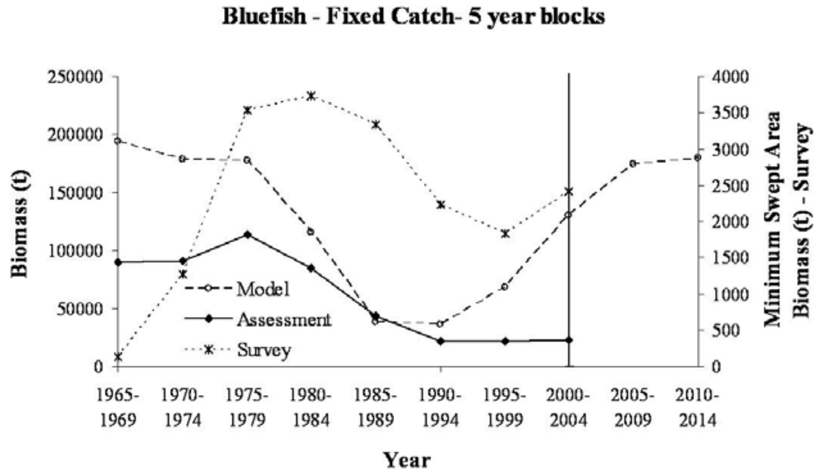


b.



c.

Figure B2. White hake (Urophycis tenuis) biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



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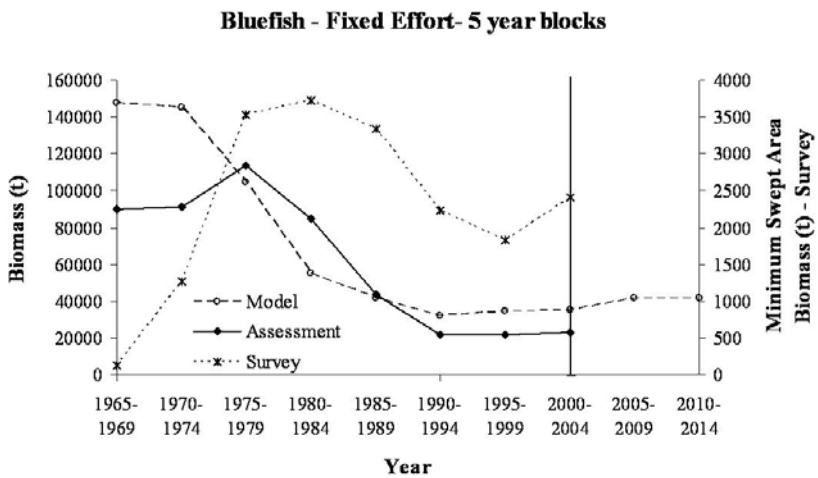
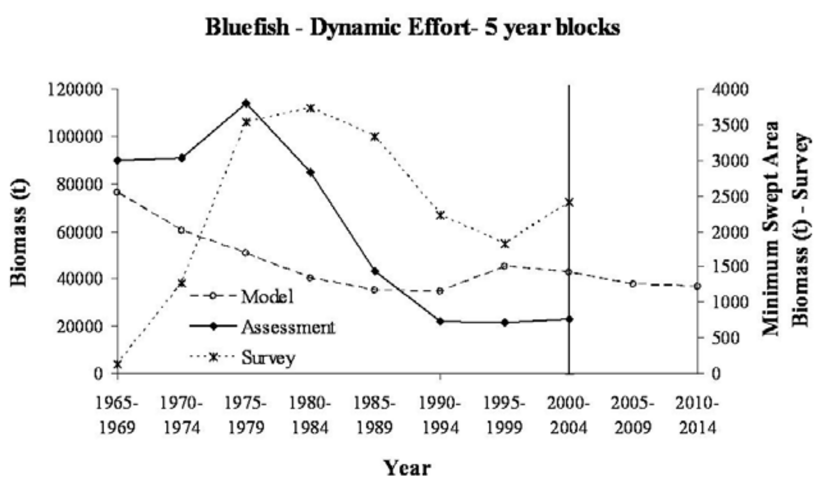
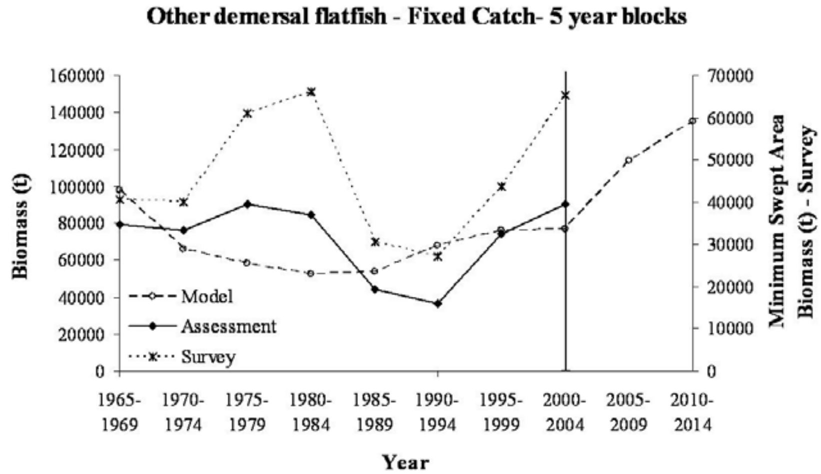


b.



c.

Figure B3. Bluefish (*Pomatomus saltatrix*) biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



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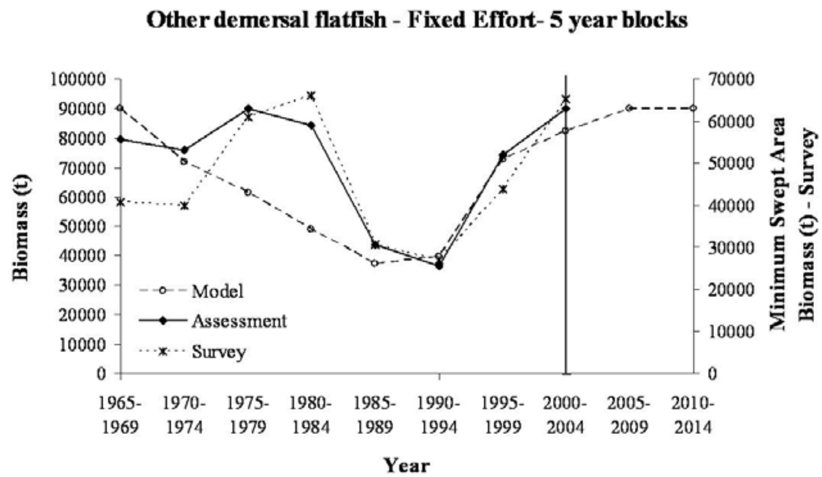
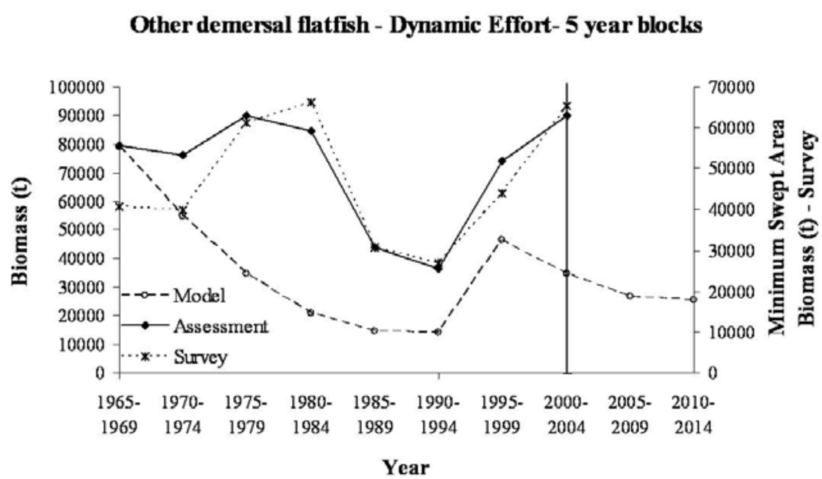
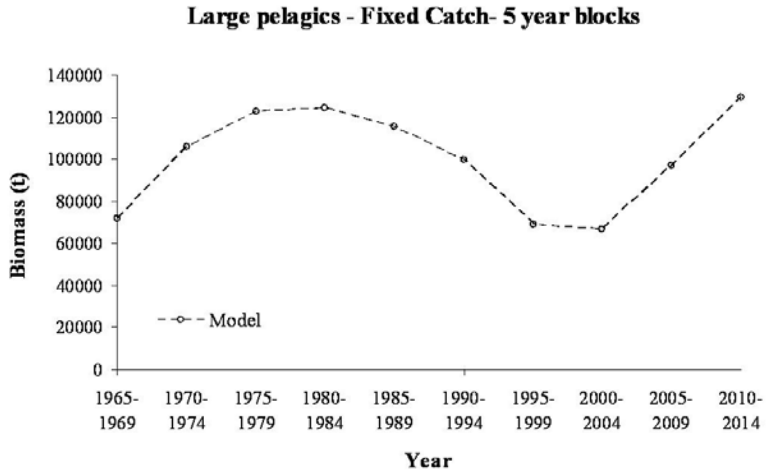


b.

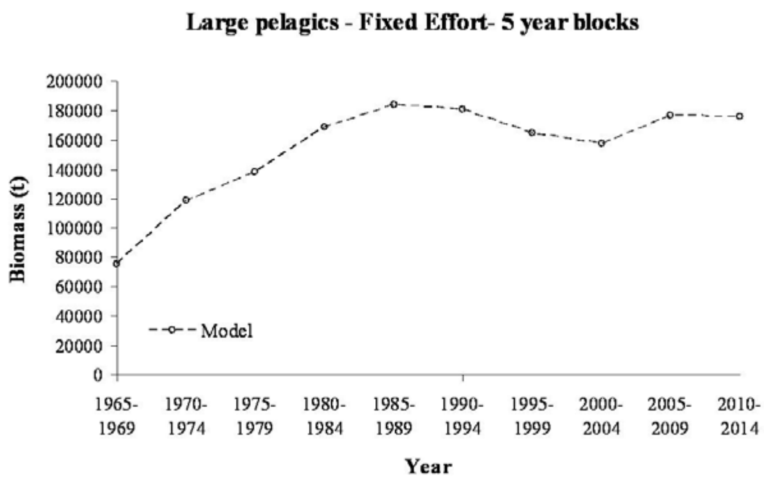


c.

Figure B4. Other demersal flatfish biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



a.



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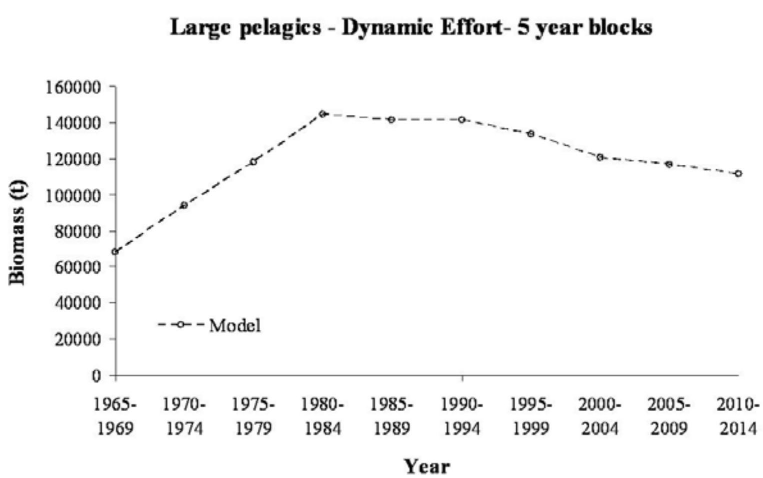
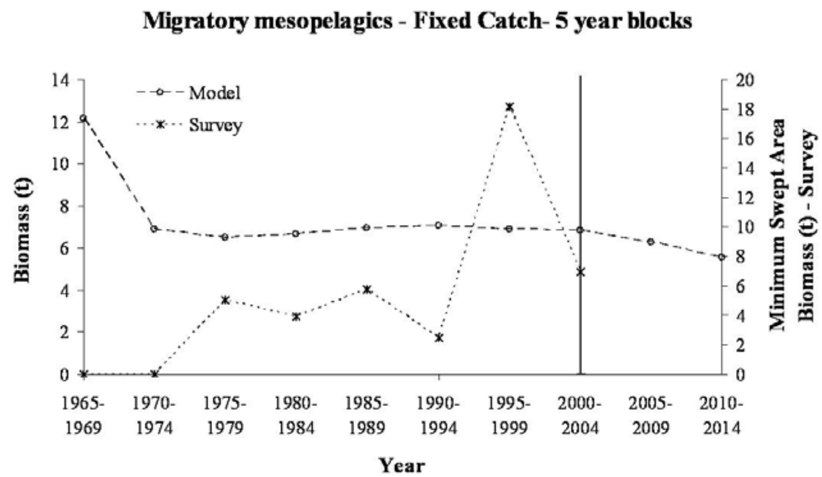
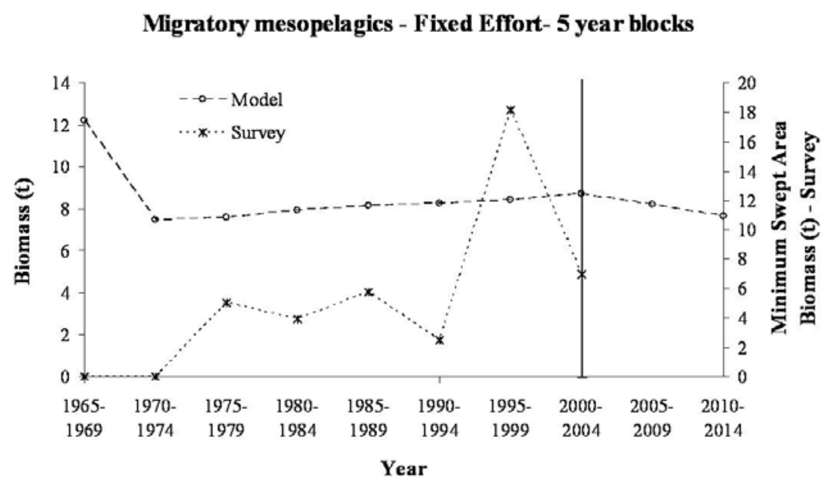


c.

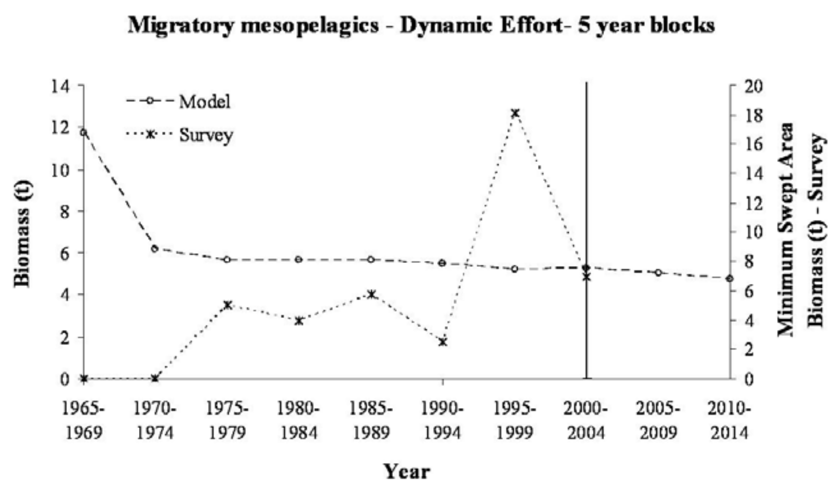
Figure B5. Large pelagics biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

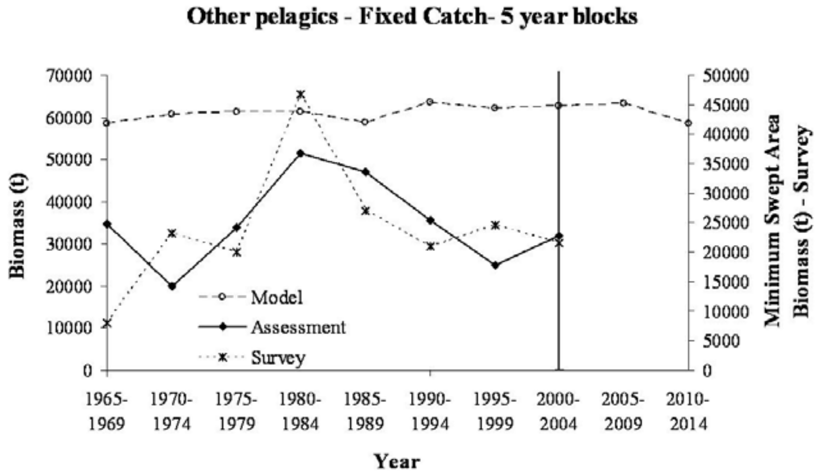


b.

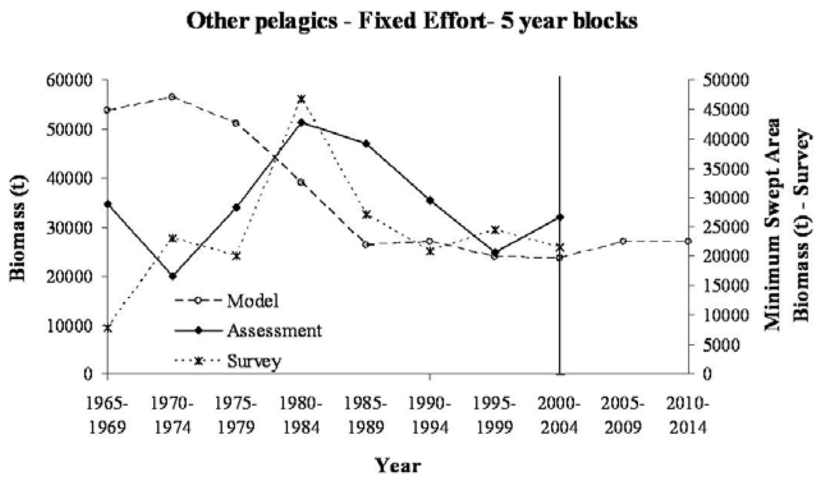


c.

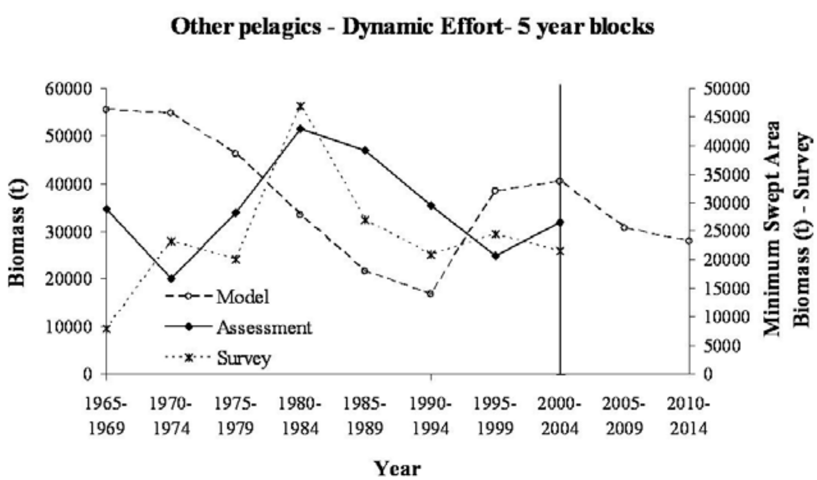
Figure B6. Migratory mesopelagics biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (survey only, no assessment time series was available). Modeled data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



a.

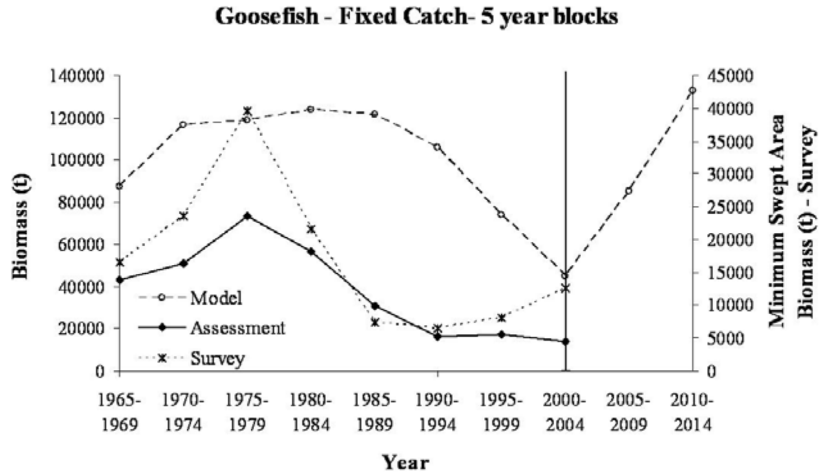


b.

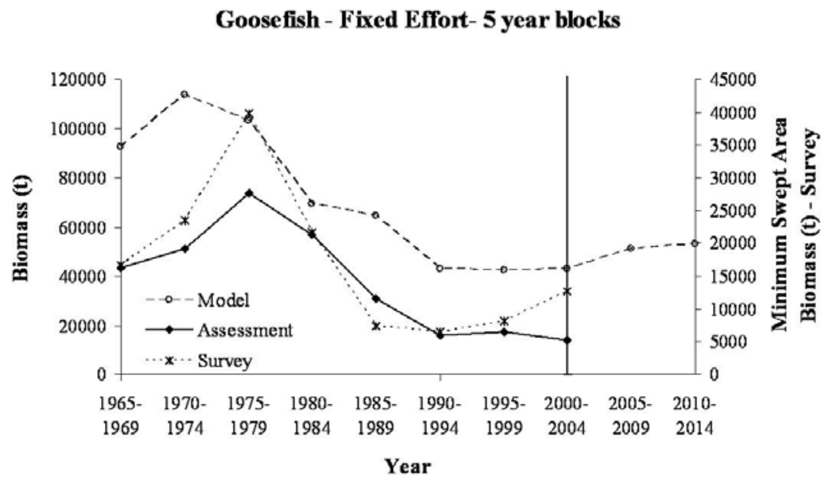


c.

Figure B7. Other pelagics biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



a.



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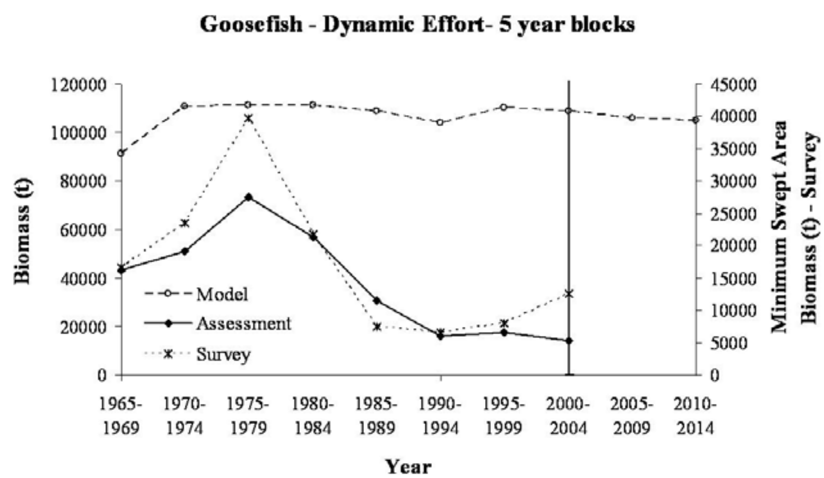
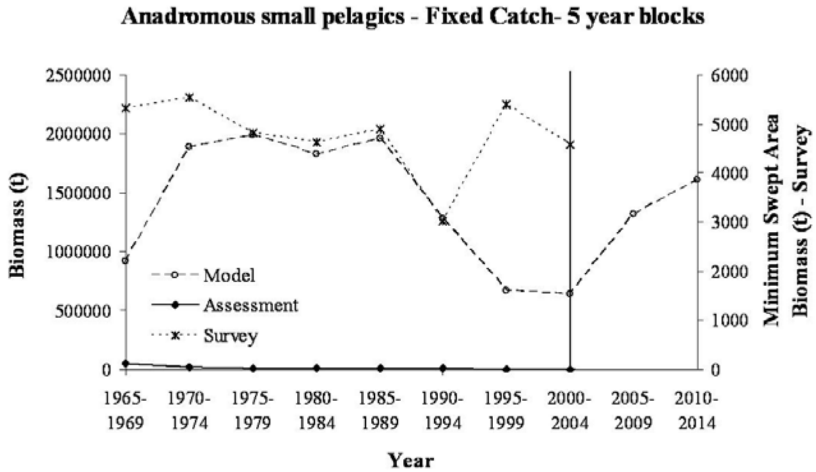
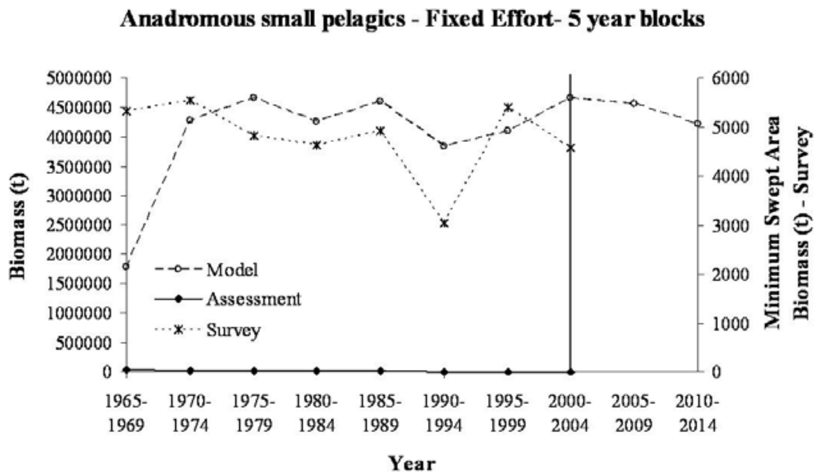


c.

Figure B8. Goosefish (*Lophius americanus*) biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



a.



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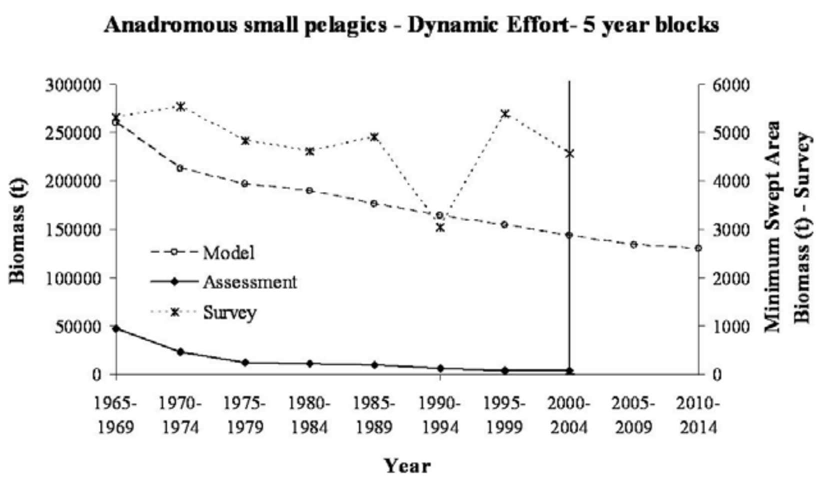
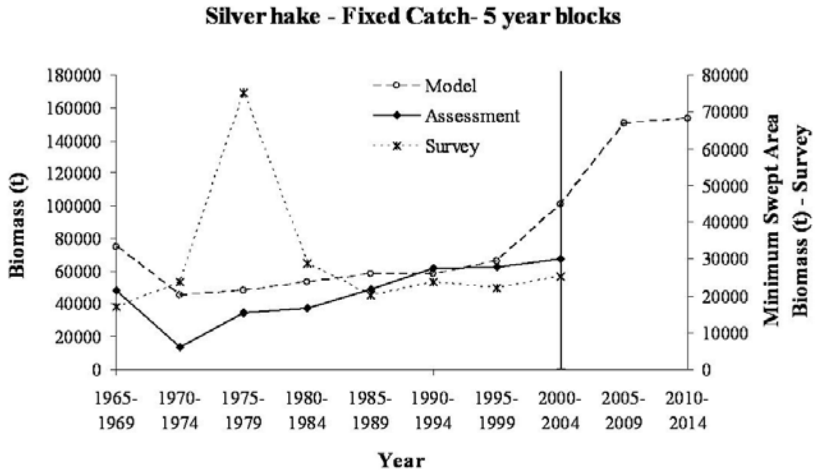
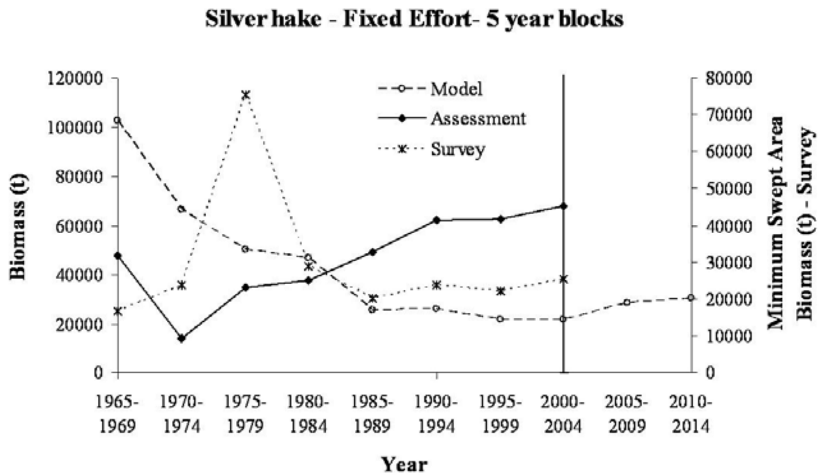


c.

Figure B9. Anadromous small pelagics biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



a.



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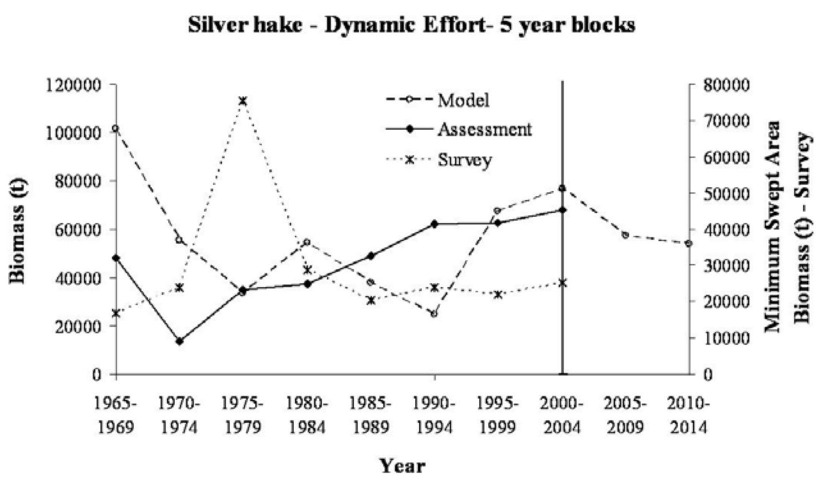
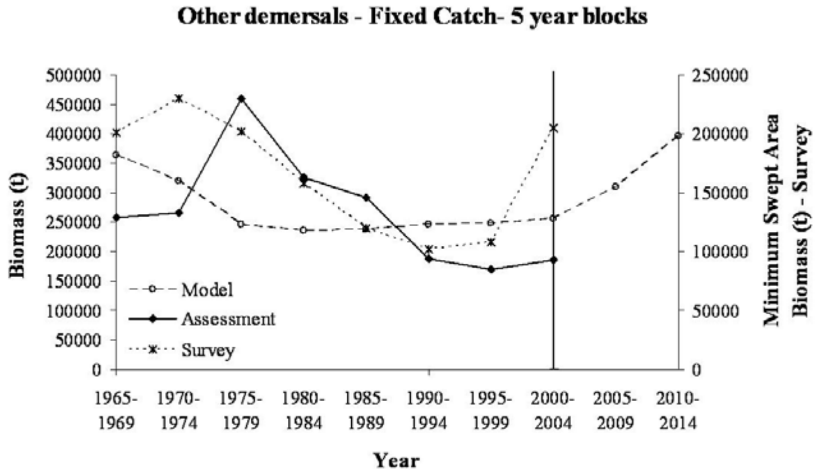


c.

Figure B10. Silver hake (*Merluccius bilinearis*) biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



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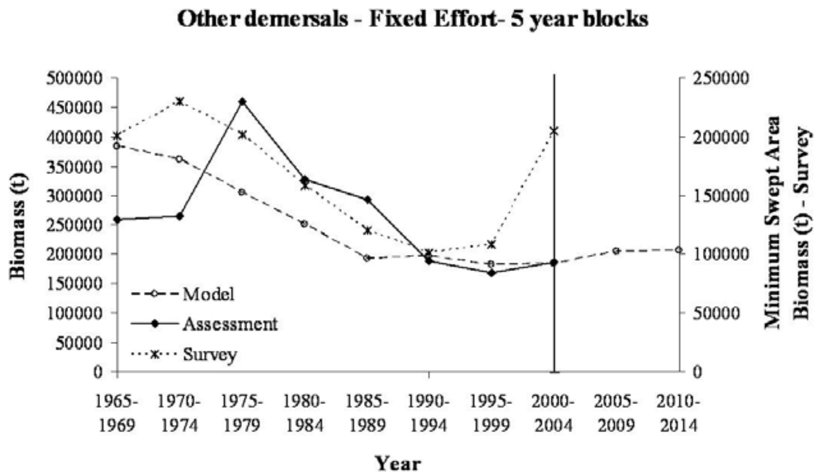

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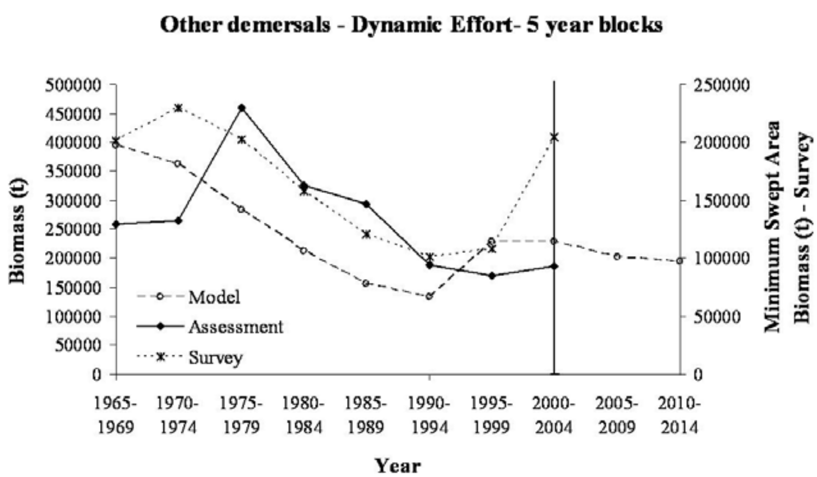
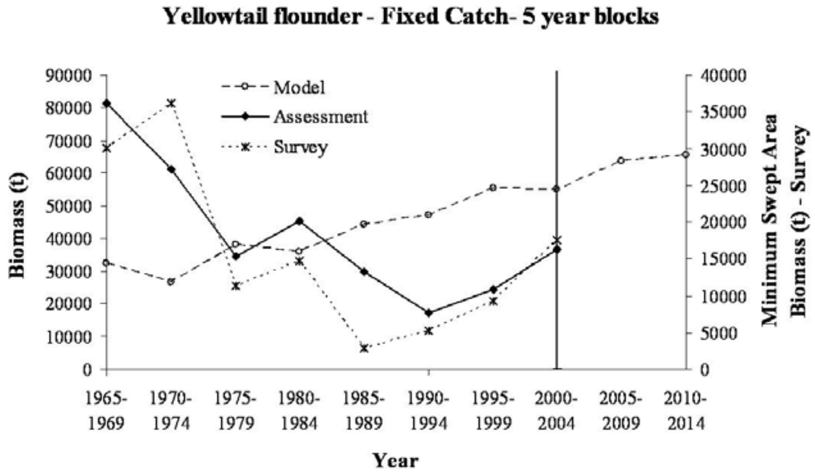
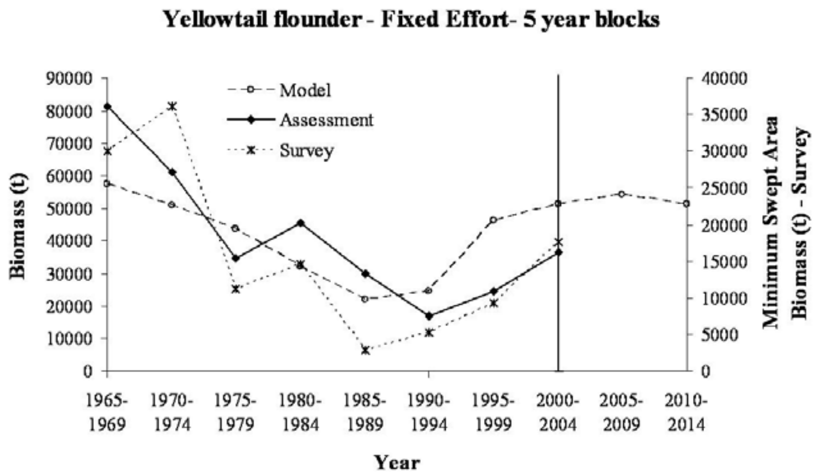


c.

Figure B11. Other demersals biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



a.



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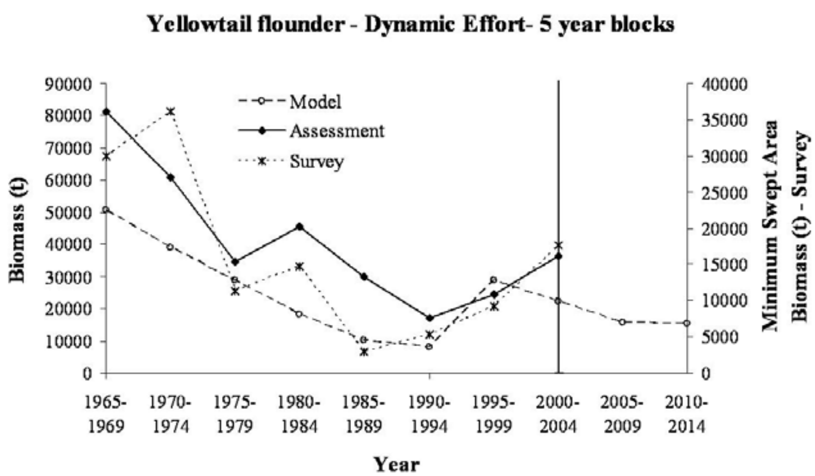
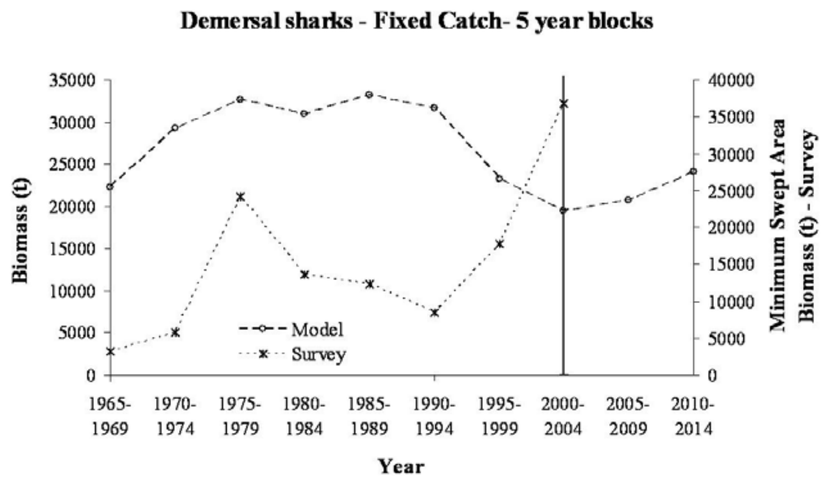
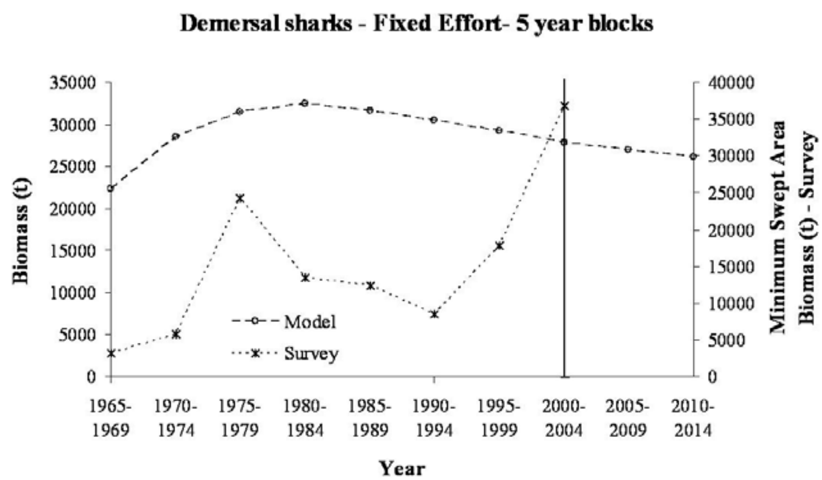


c.

Figure B12. Yellowtail flounder (*Limanda ferruginea*) biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



a.



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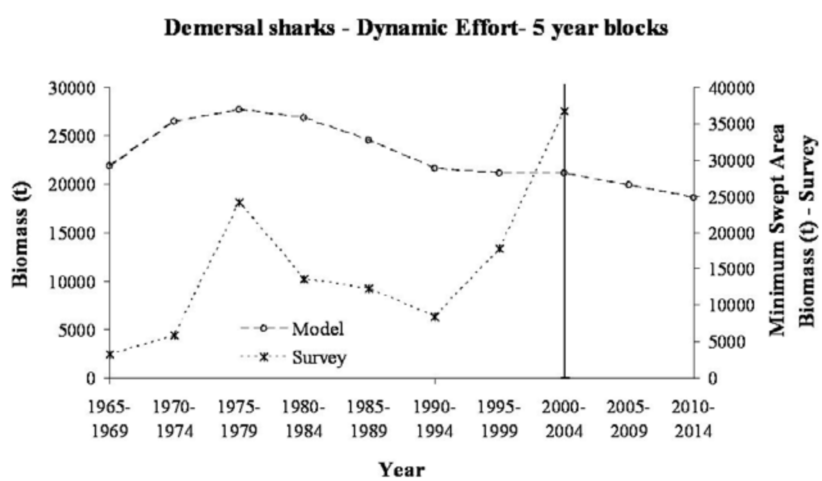
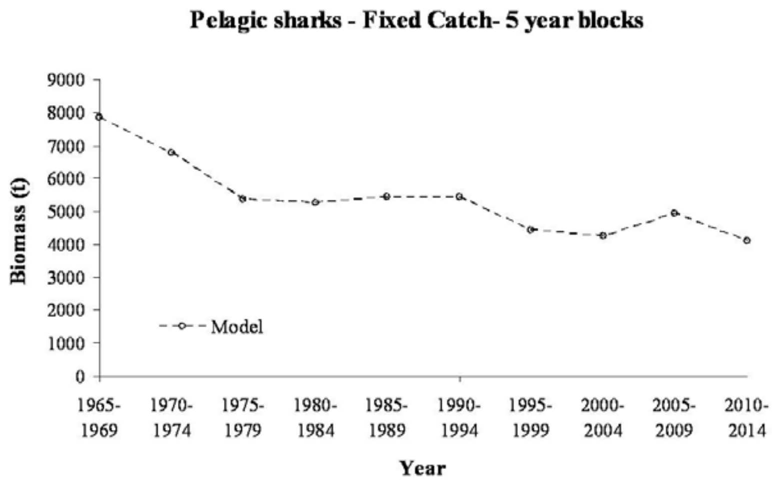


c.

Figure B13. Demersal sharks biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (survey only, no assessment time series was available). Modeled data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



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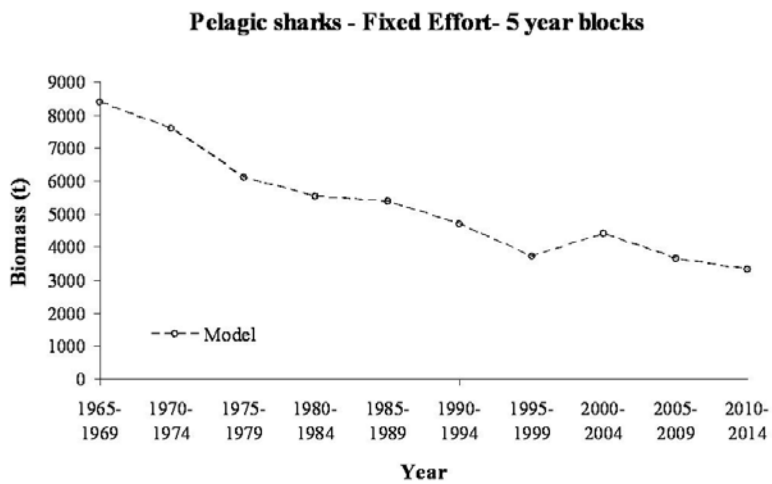
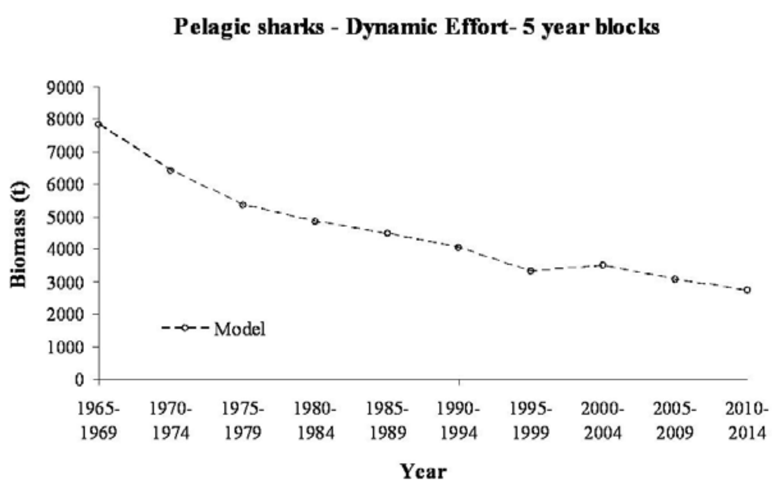


b.



c.

Figure B14. Pelagic sharks biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.

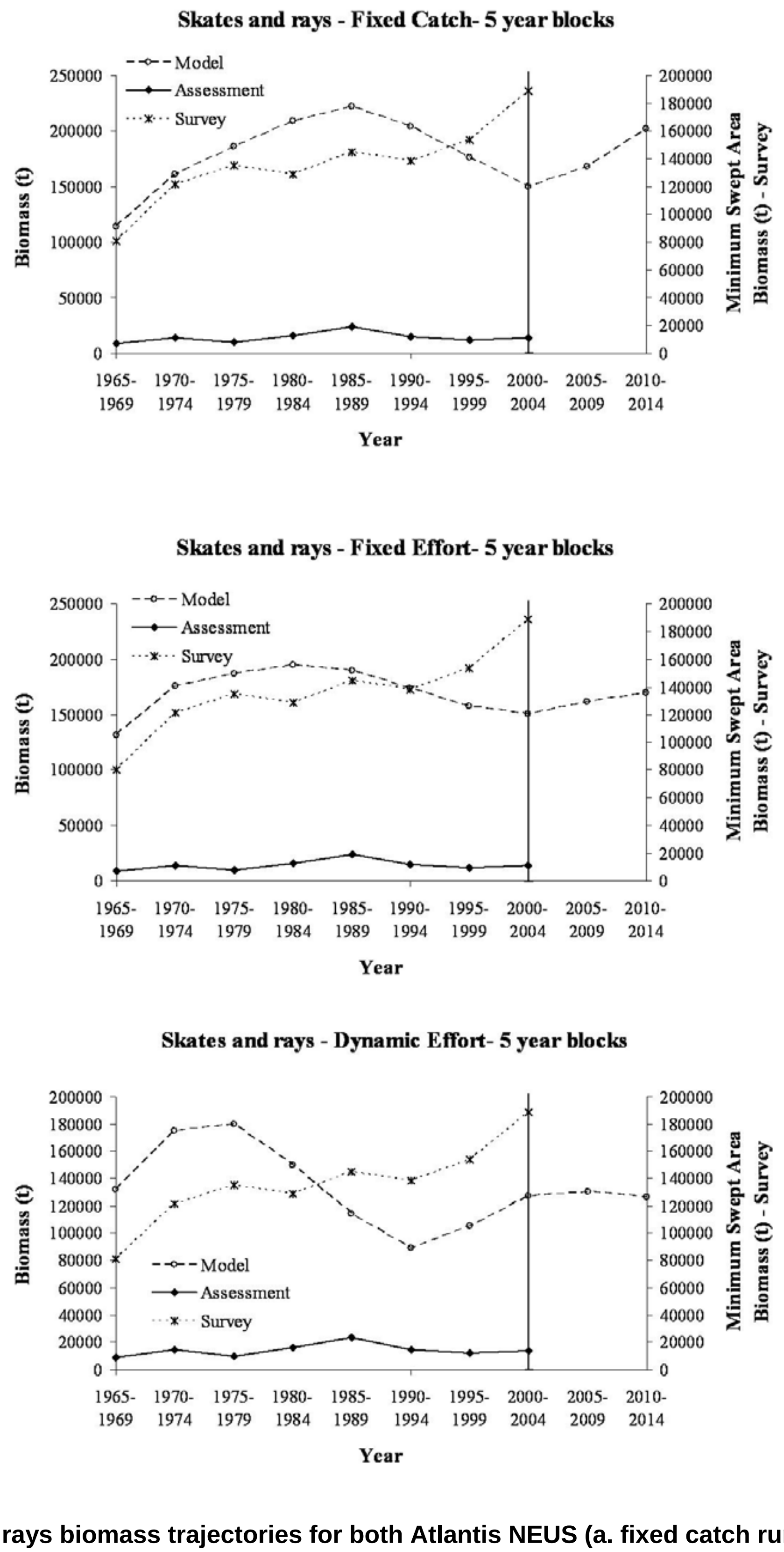
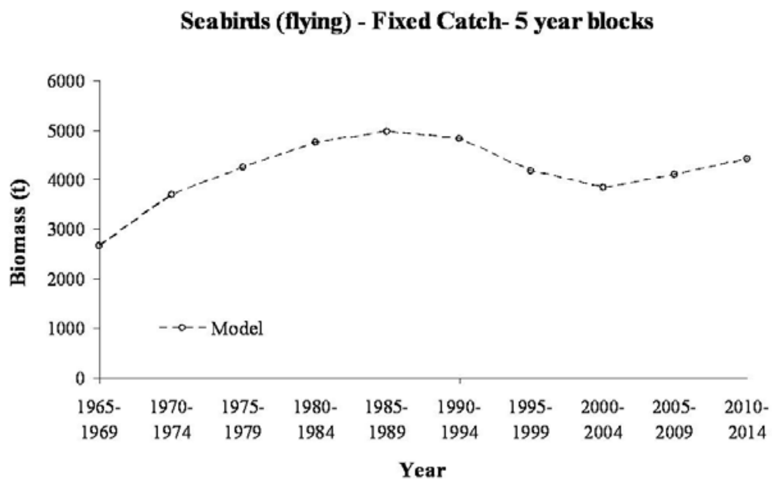
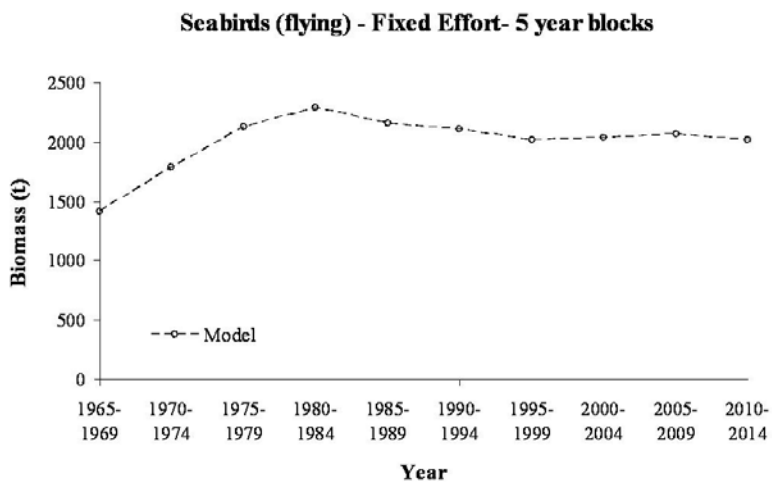


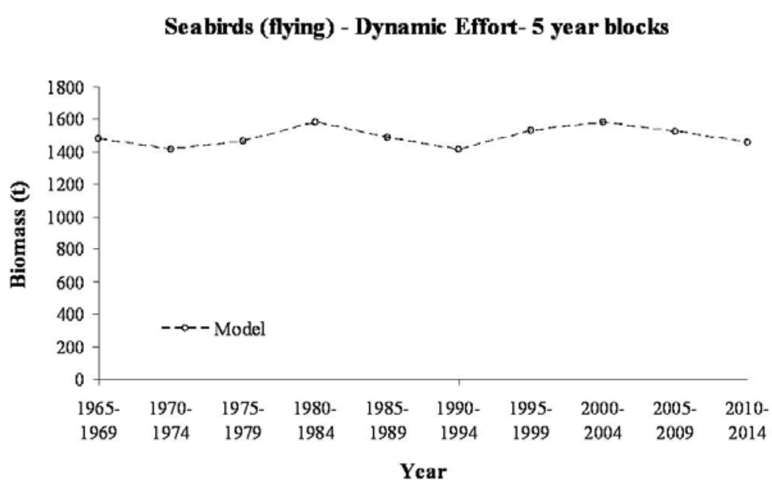
Figure B15. Skates and rays biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



a.

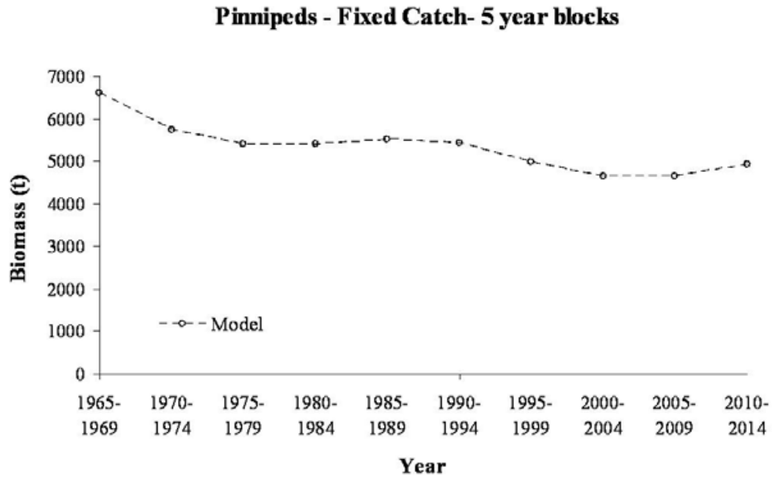


b.

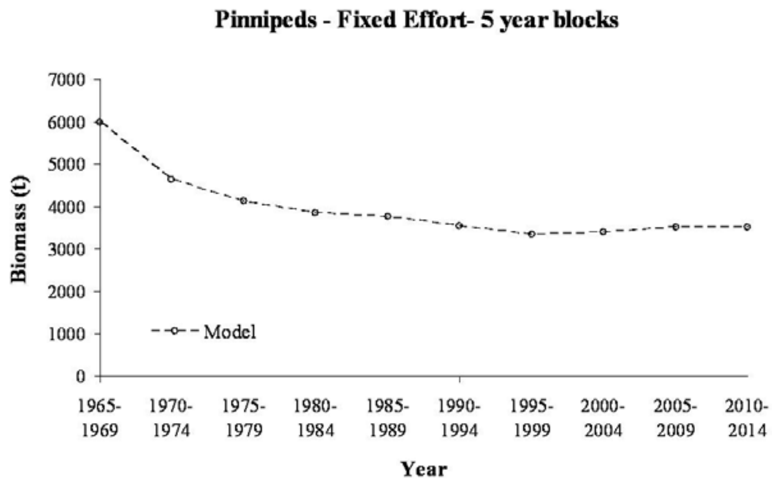


c.

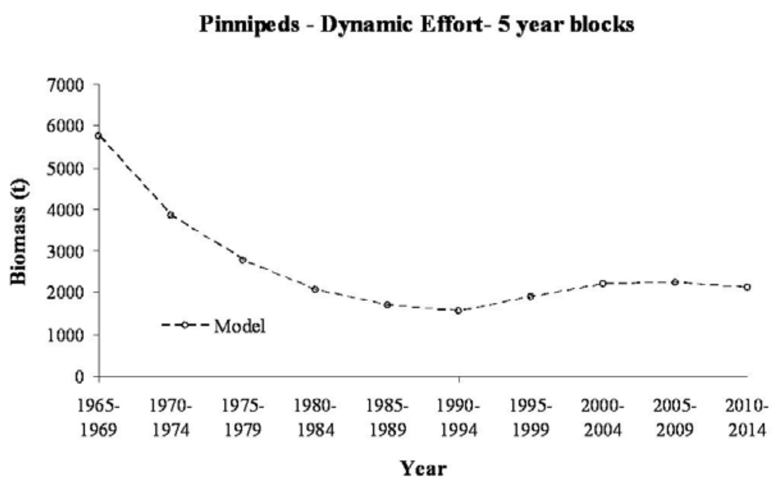
Figure B.16. Seabirds biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.



b.



c.

Figure B17. Pinnipeds biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.

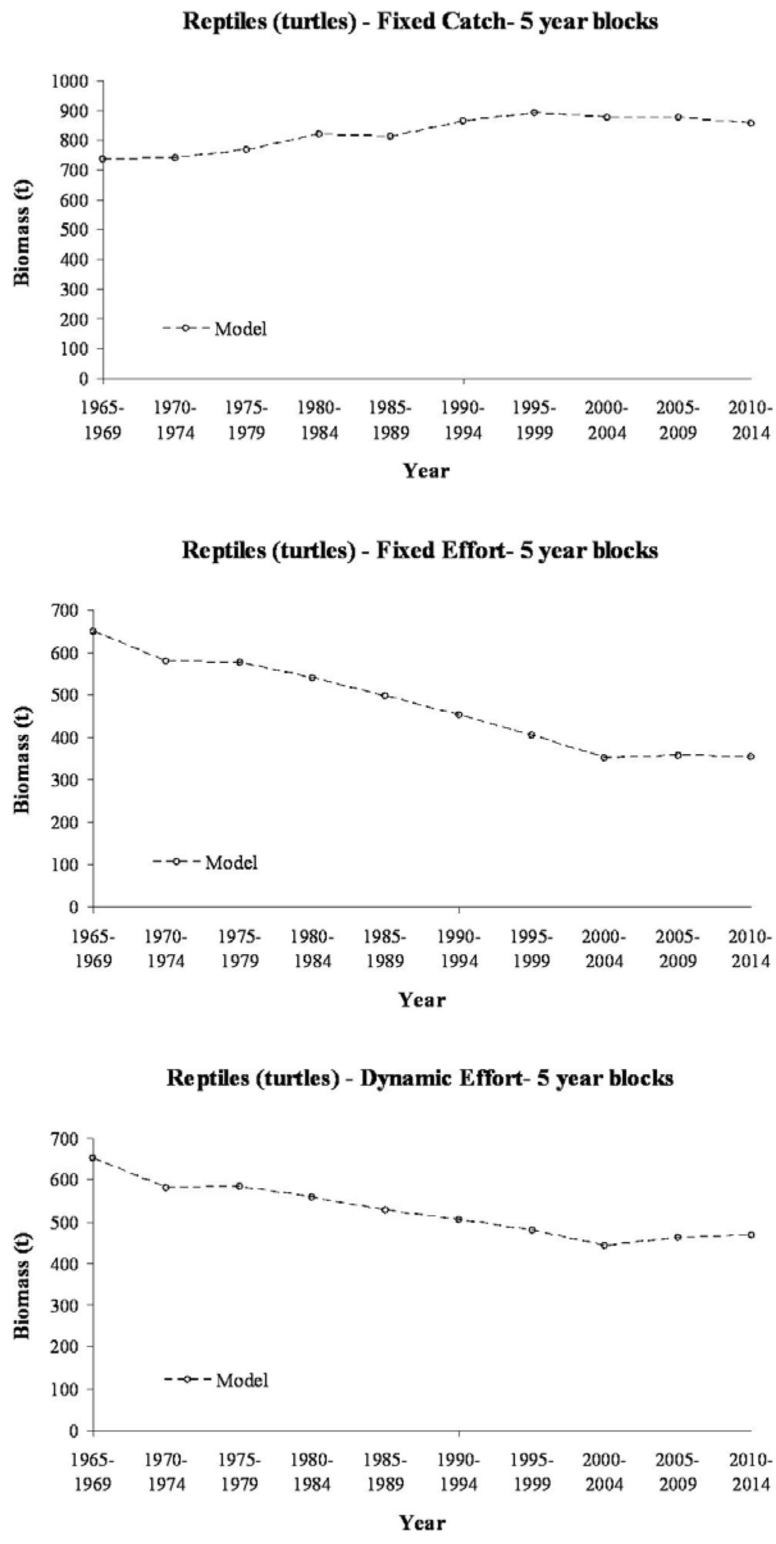
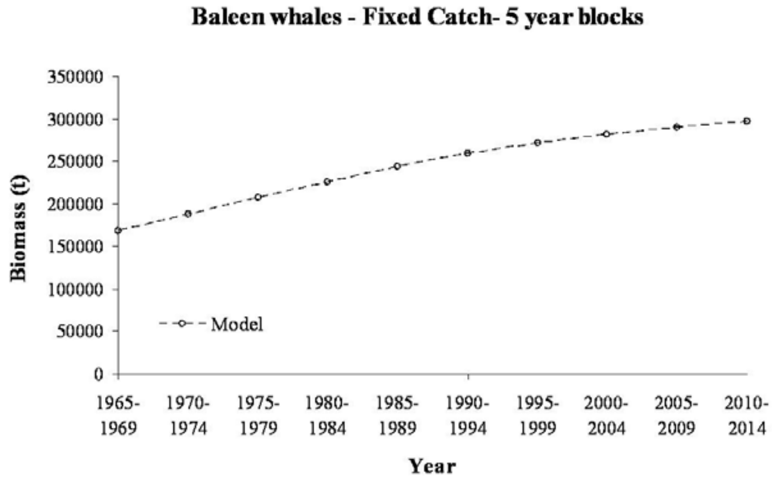
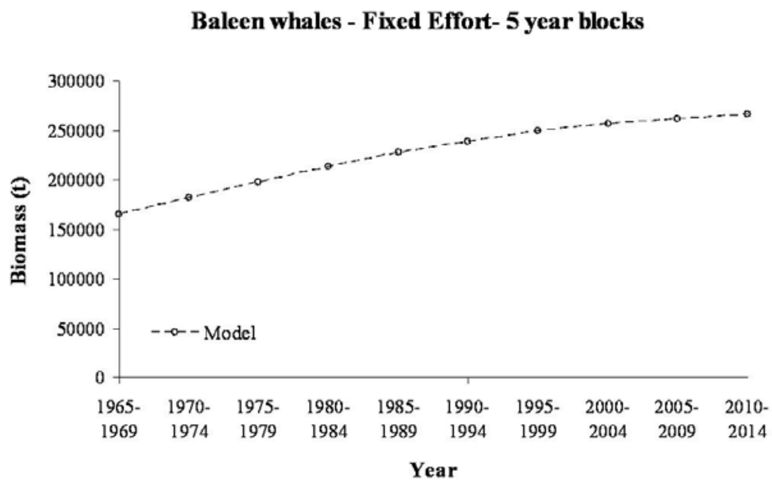


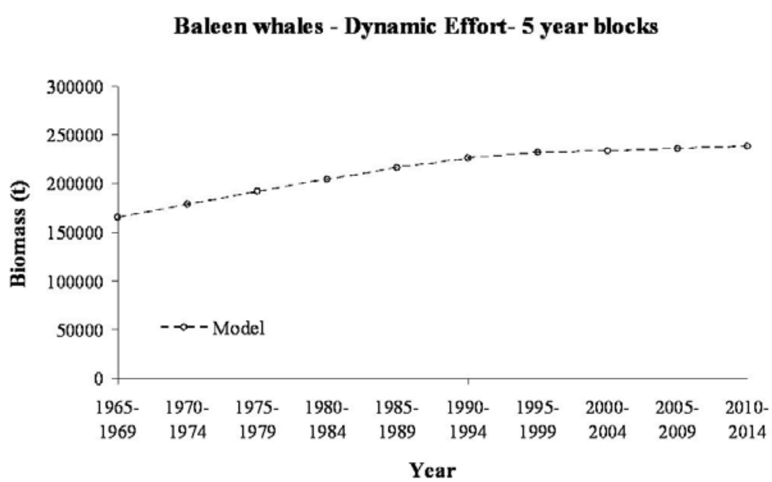
Figure B18. Reptiles biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

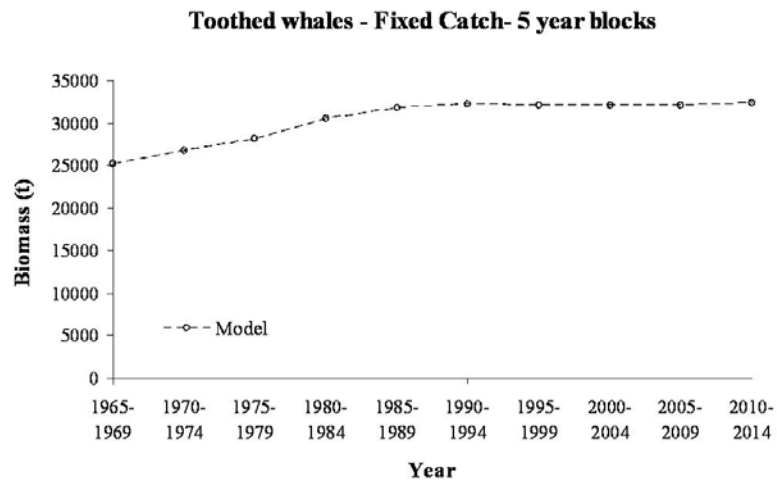


b.

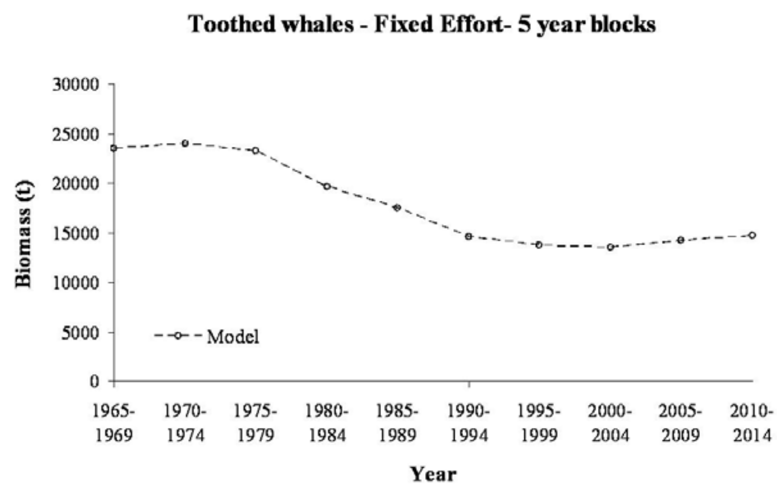


c.

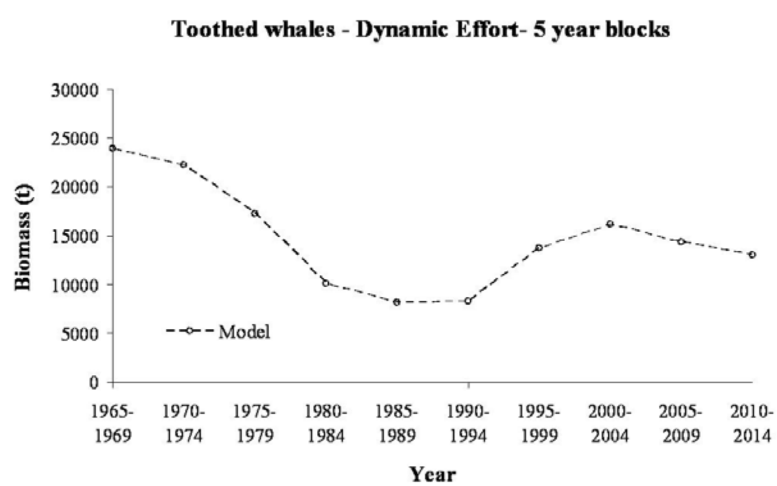
Figure B19. Baleen whales biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

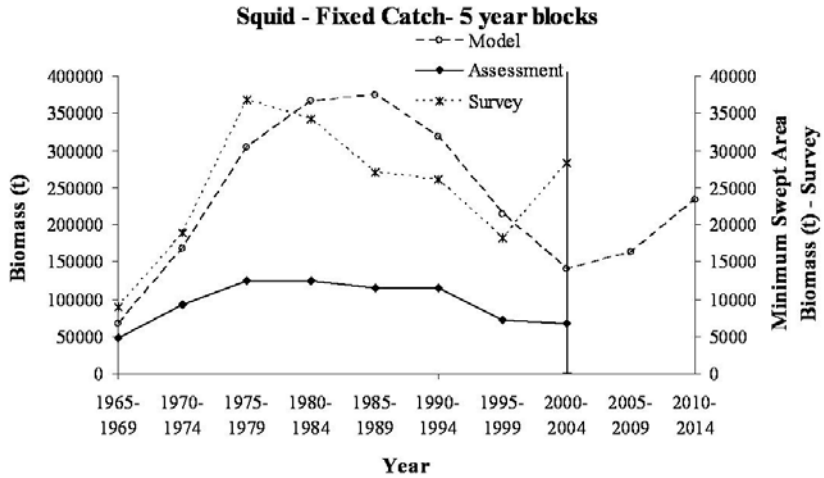


b.

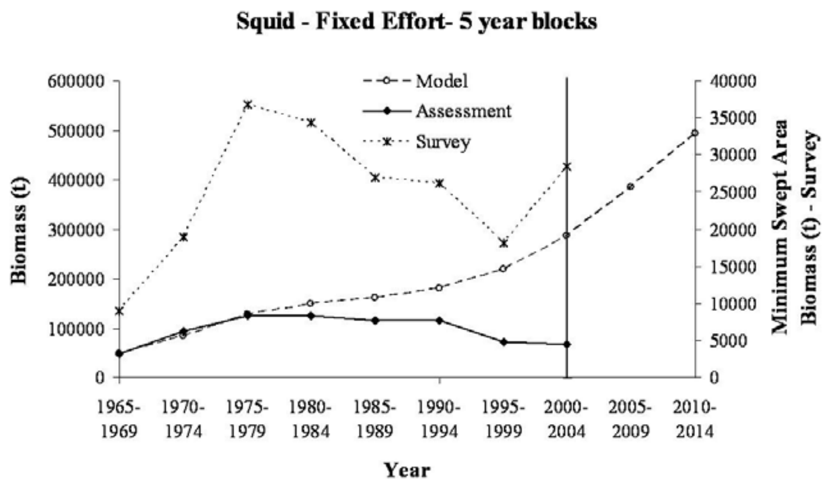


c.

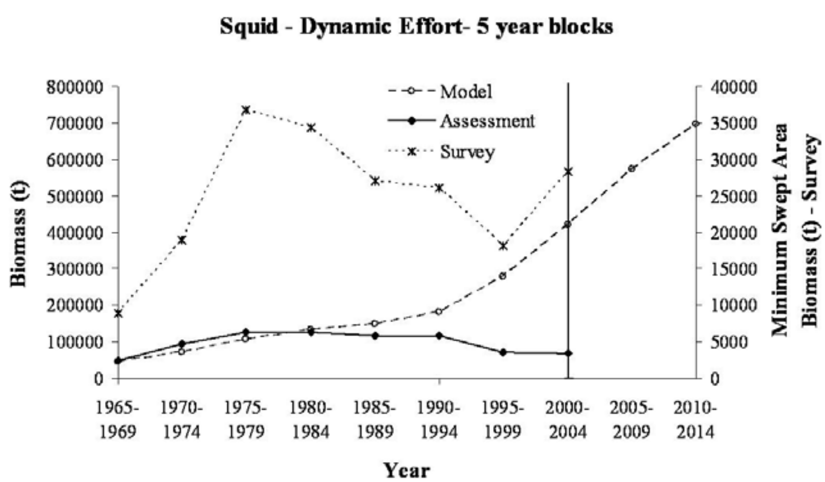
Figure B20. Toothed whales biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

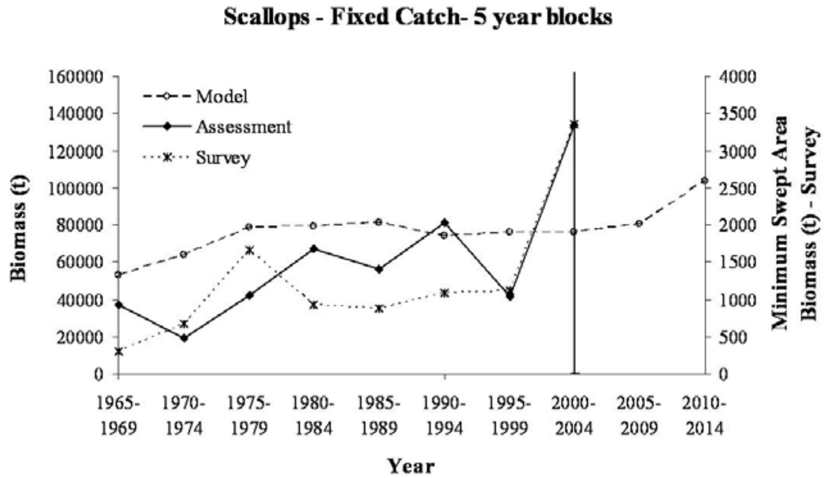


b.

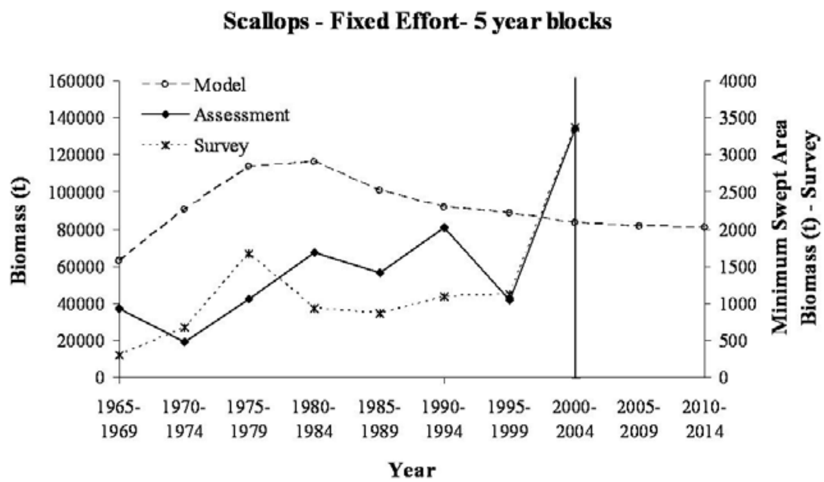


c.

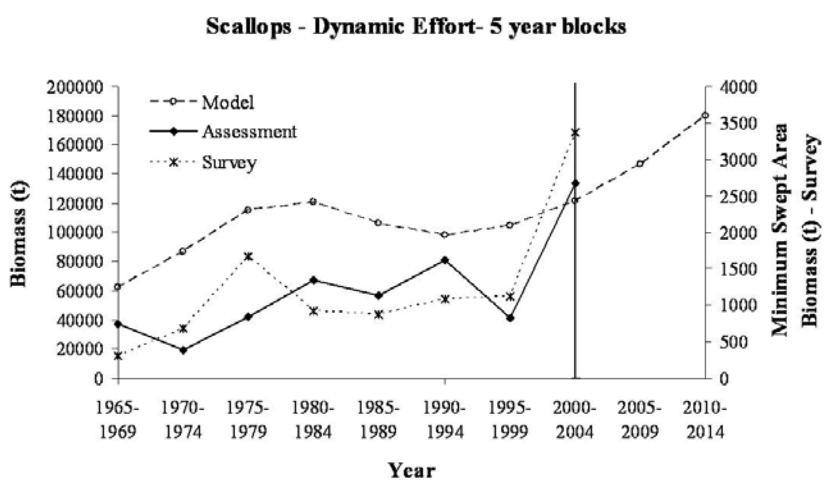
Figure B21. Squid biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



a.

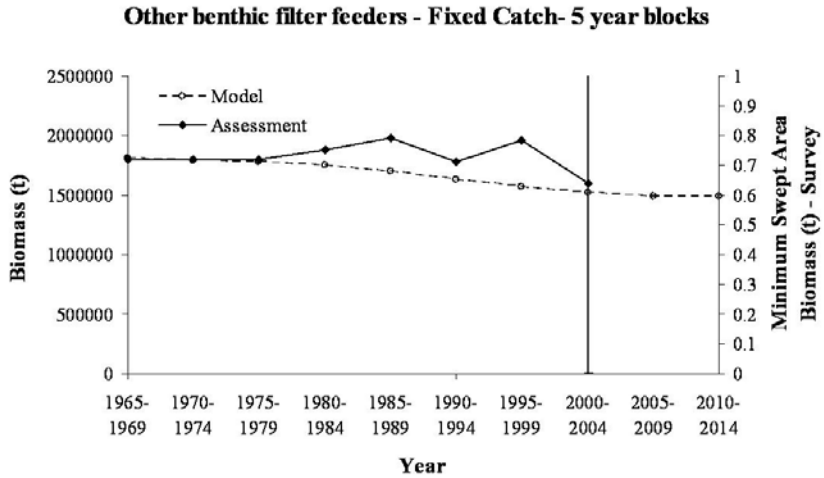


b.

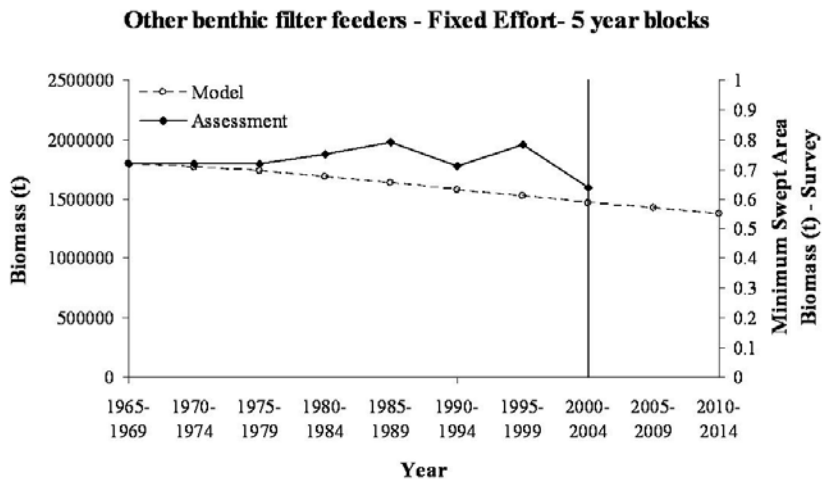


c.

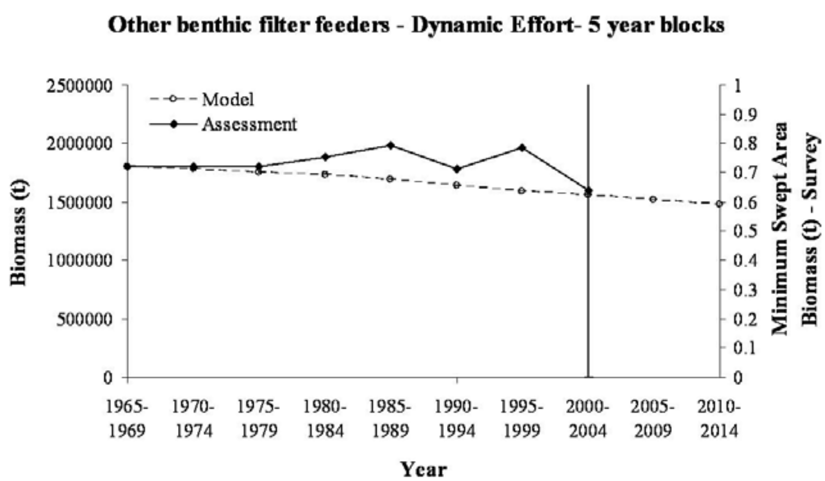
Figure B22. Sea scallop (*Placopecten magellanicus*) biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



a.

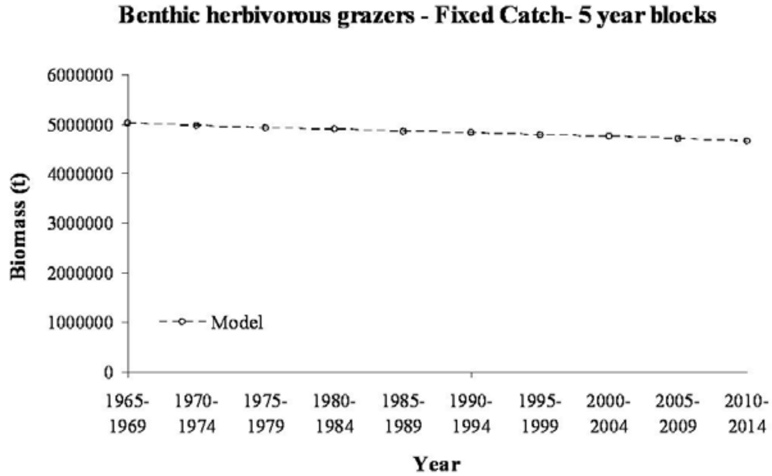


b.

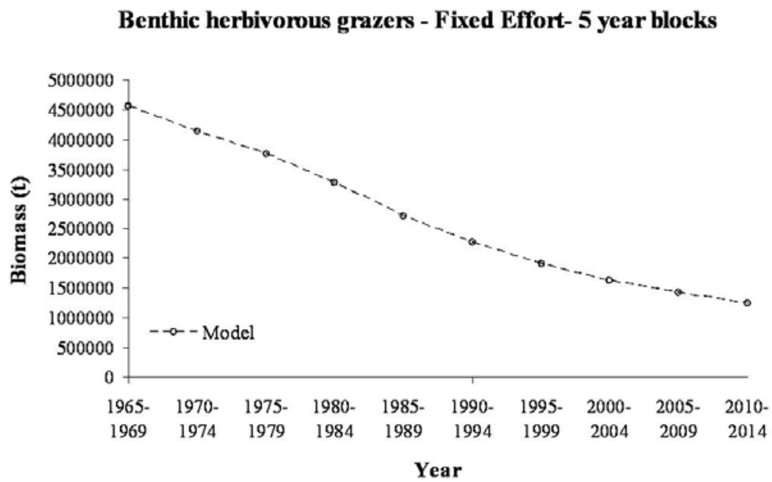


c.

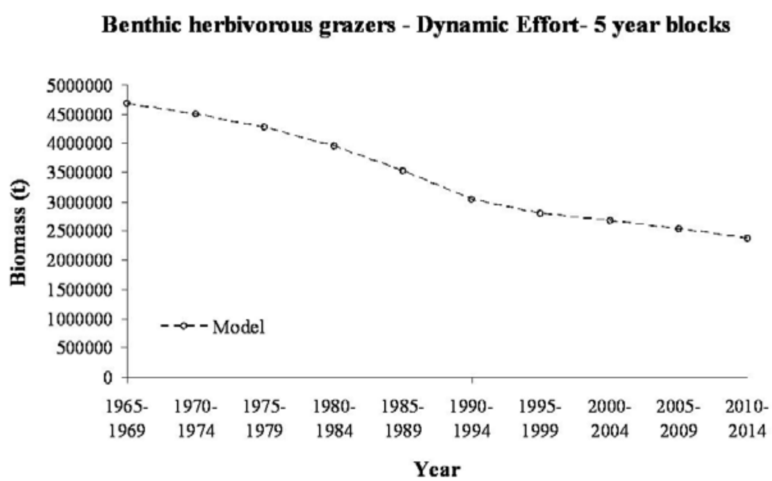
Figure B23. Other benthic filter feeders biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment only, no survey time series was available).



a.

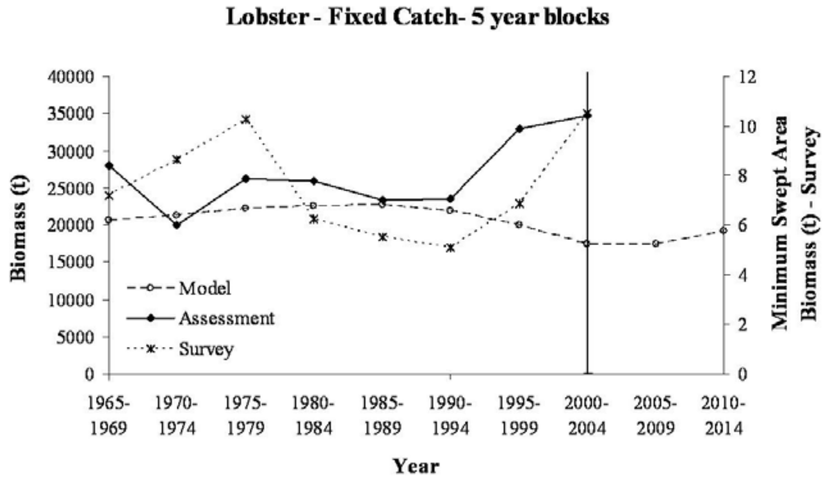


b.

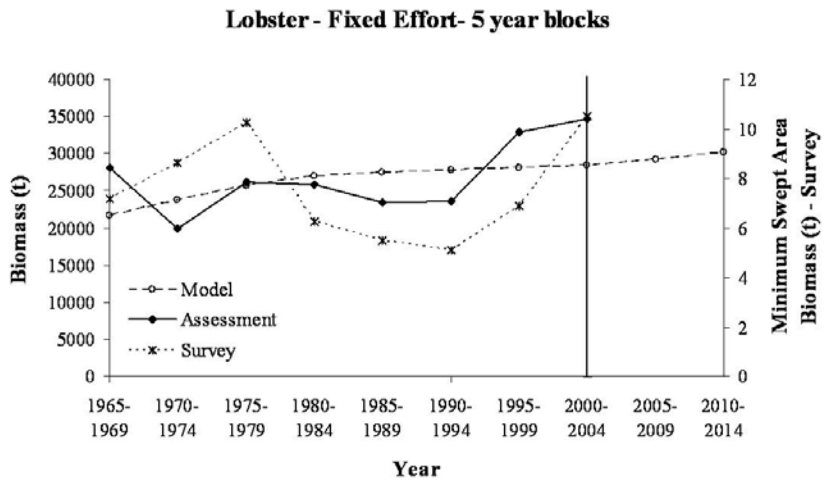


c.

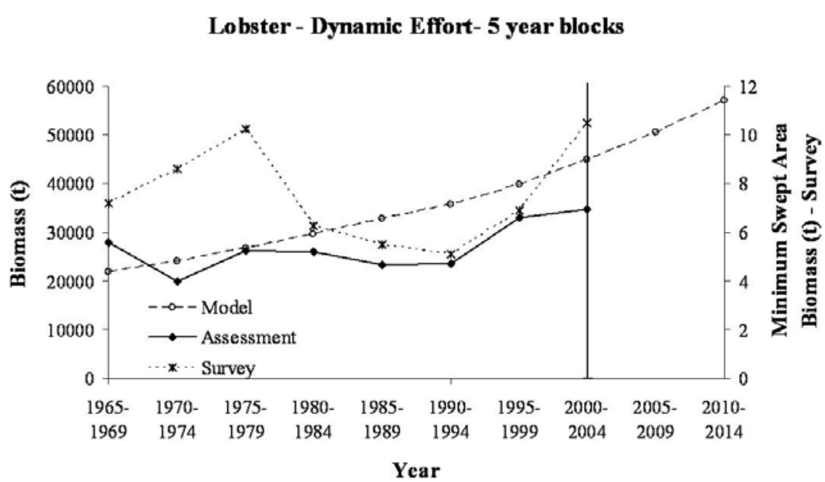
Figure B24. Benthic herbivorous grazers biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

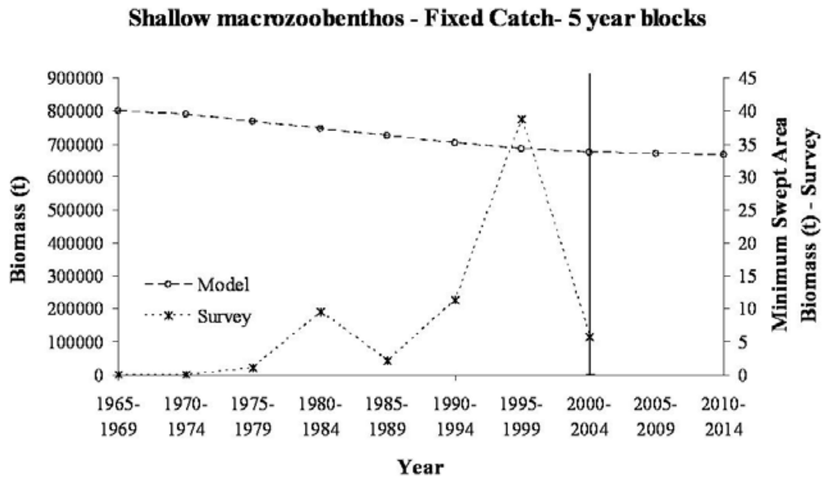


b.

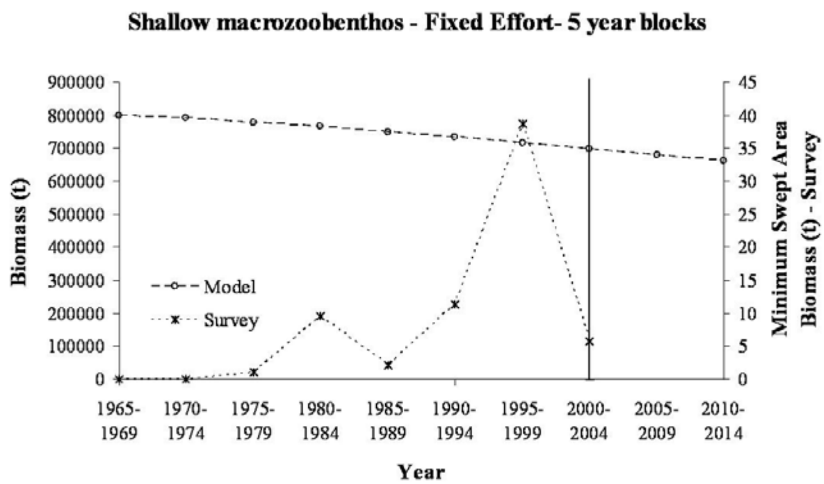


c.

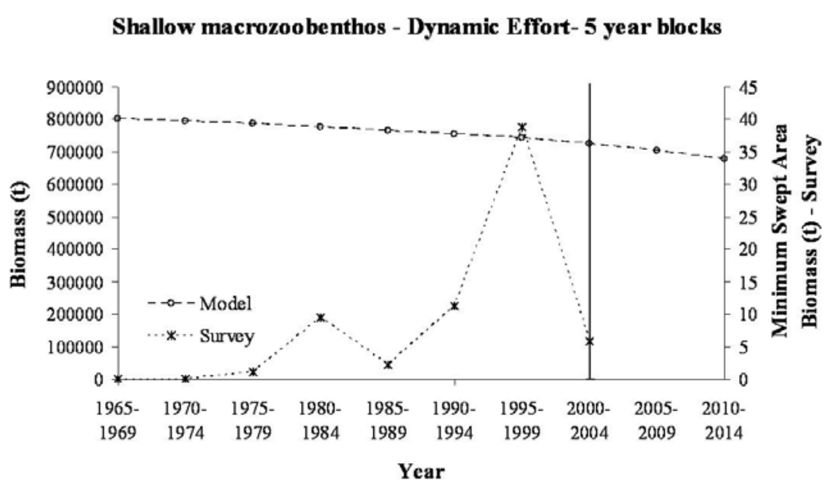
Figure B25. Lobster (*Homarus americanus*) biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (assessment and survey). Modeled and assessment data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



a.

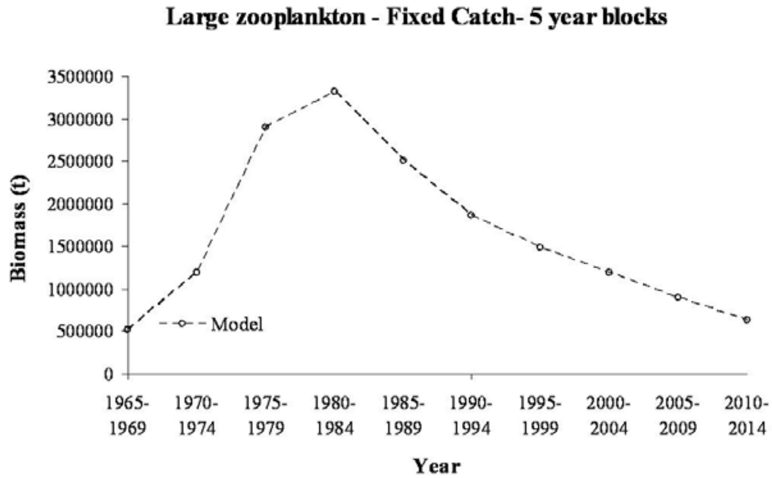


b.

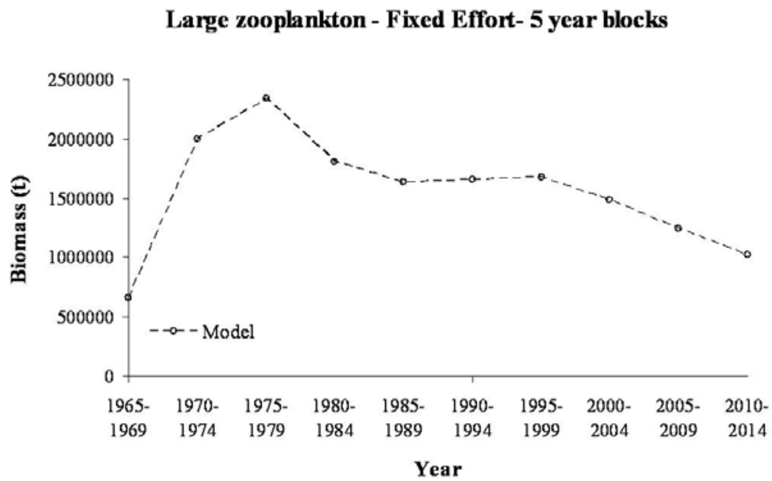


c.

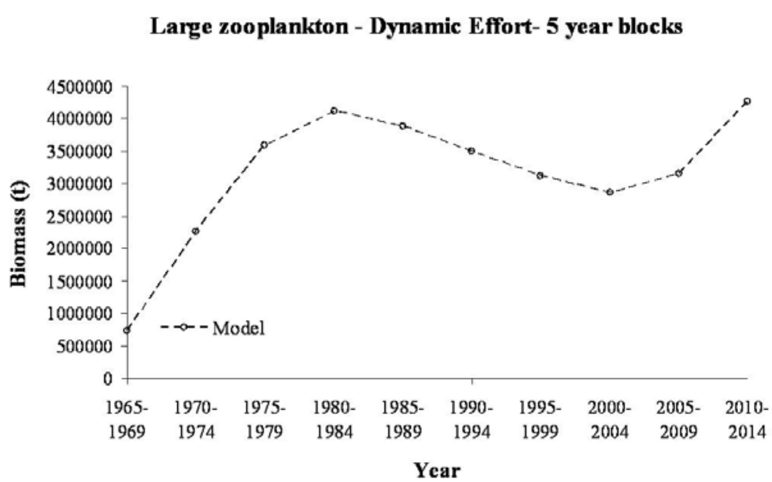
Figure B26. Shallow macrozoobenthos biomass trajectories for both Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run) and observed time series (survey only, no assessment time series was available). Modeled data are scaled to the left Y-axis while survey data are scaled to the right Y-axis.



a.

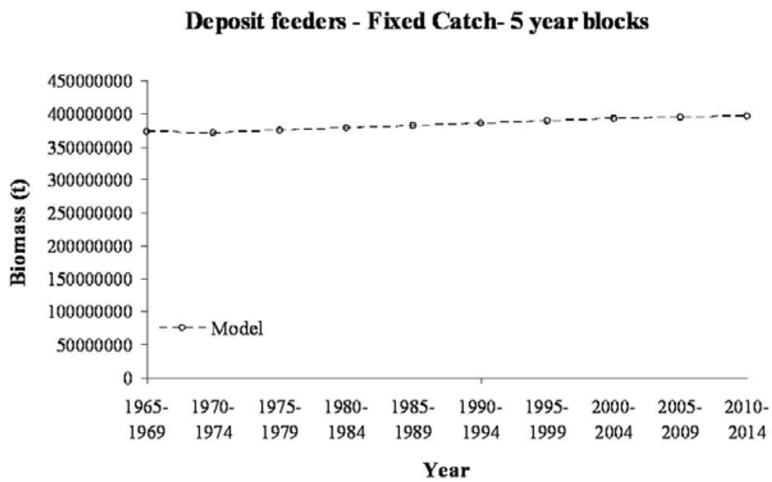


b.

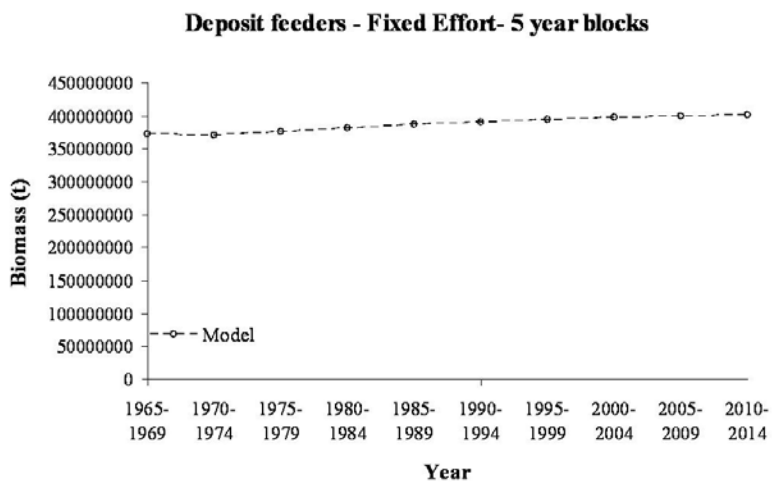


c.

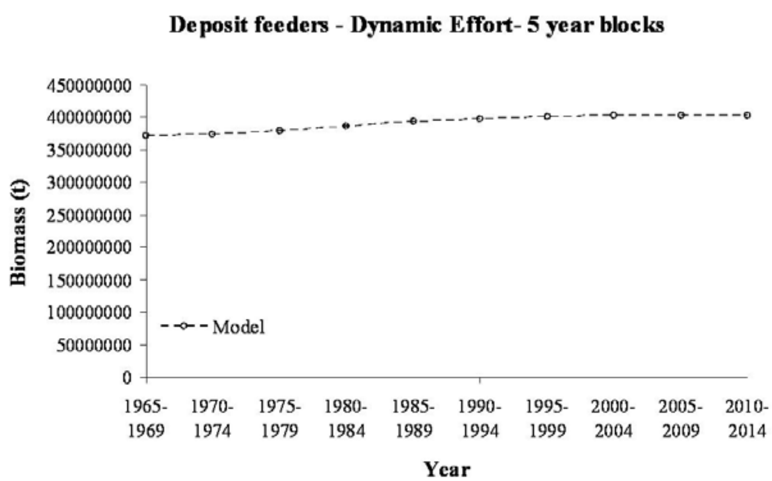
Figure B27. Large zooplankton biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

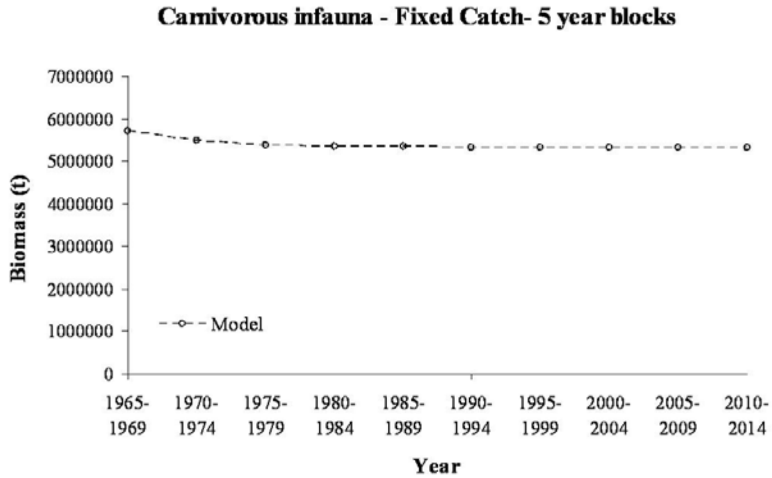


b.

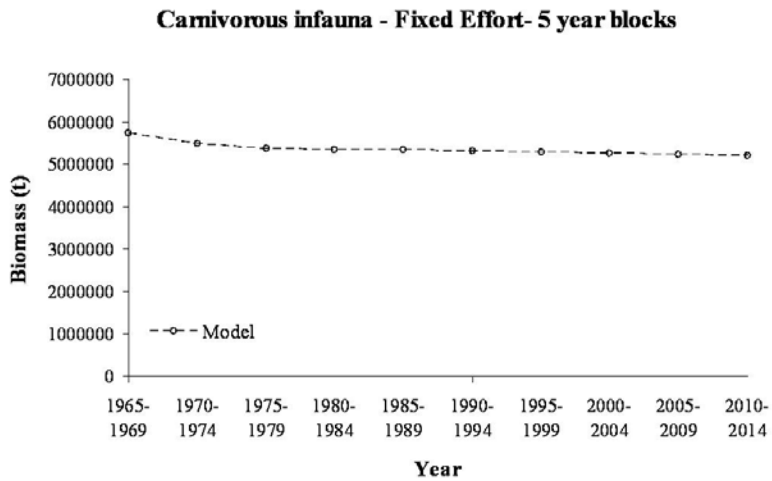


c.

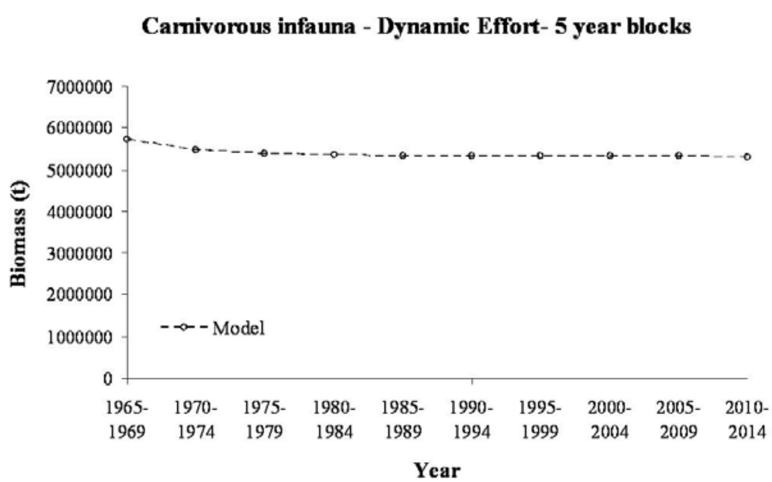
Figure B28. Deposit feeders biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

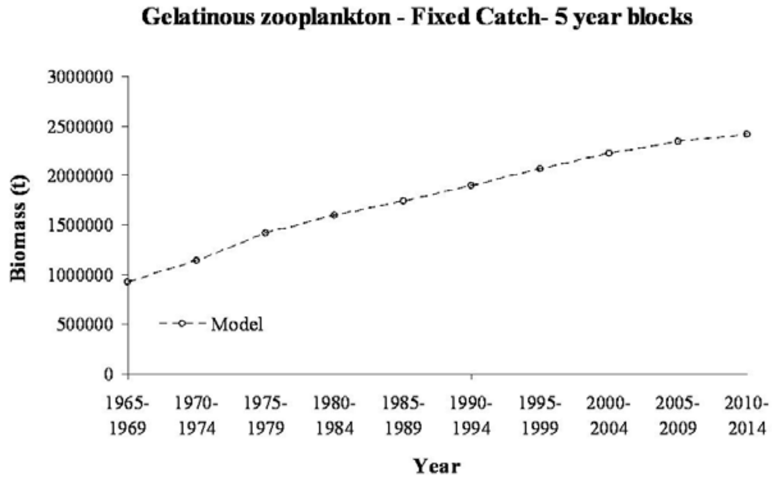


b.

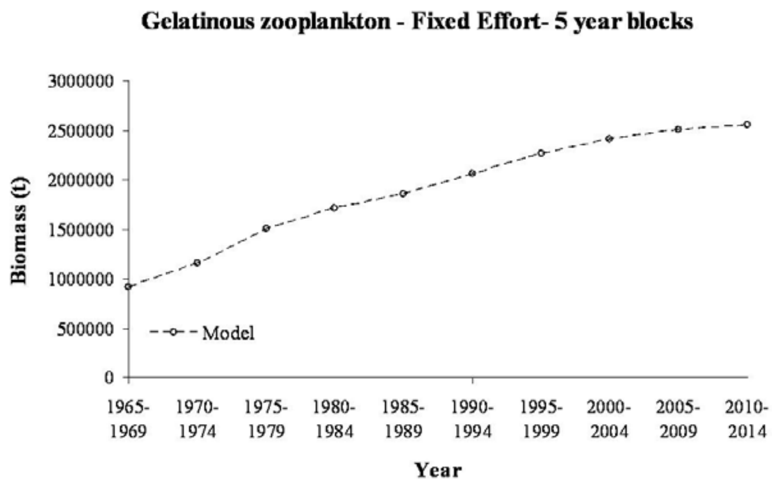


c.

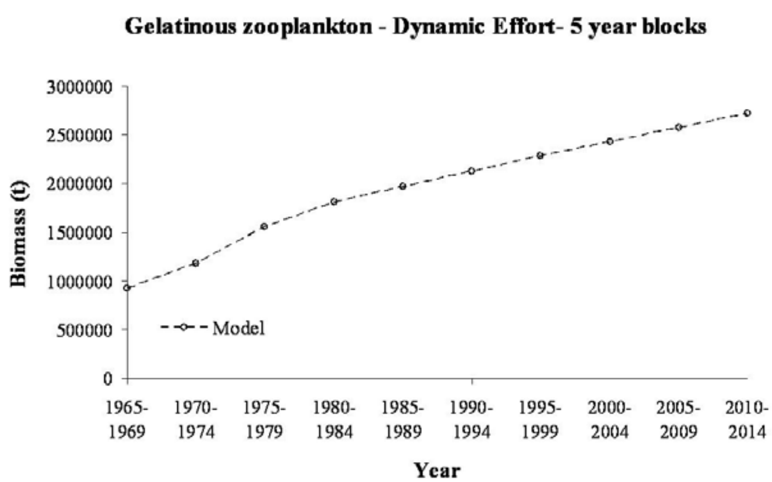
Figure B29. Carnivorous infauna biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

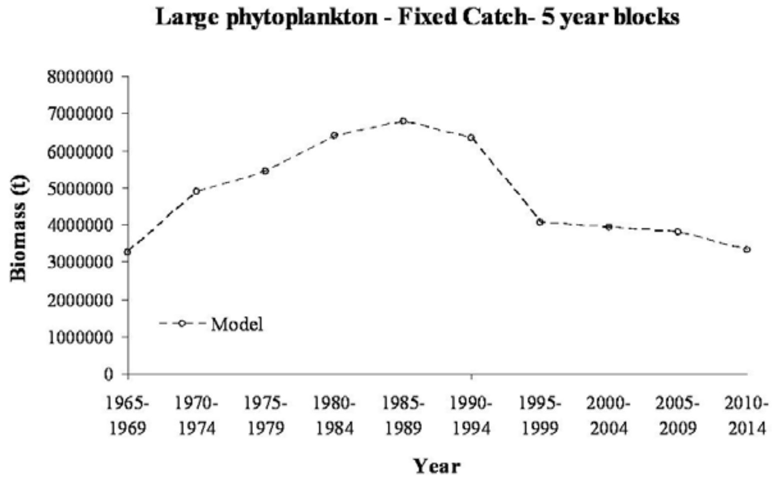


b.

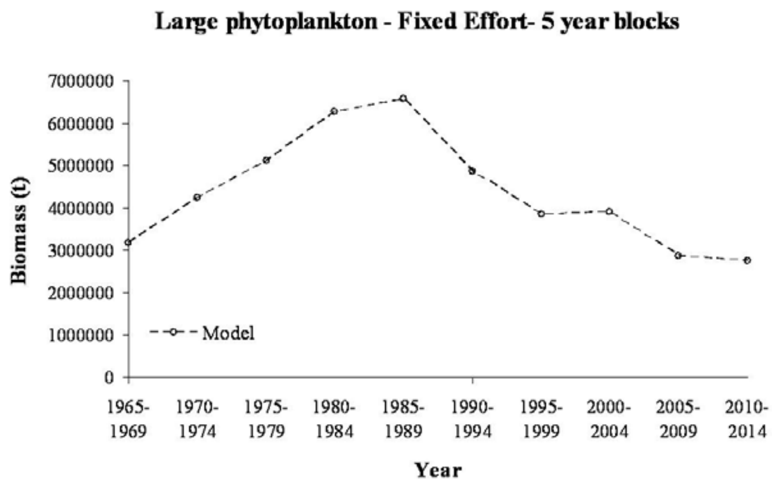


c.

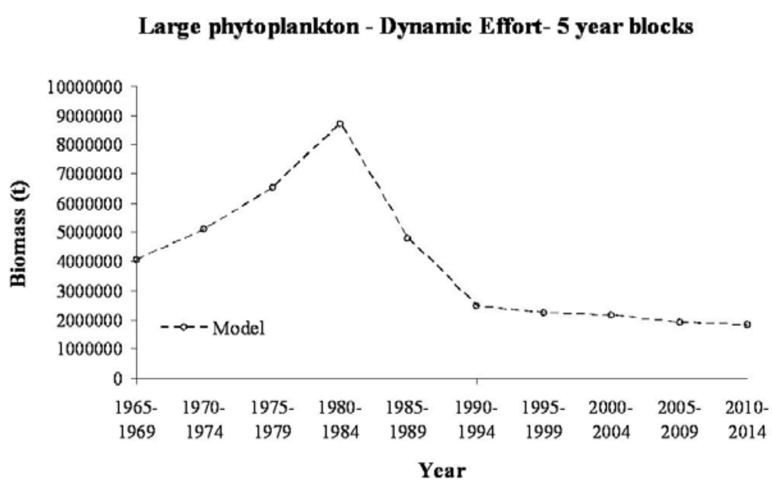
Figure B30. Gelatinous zooplankton biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

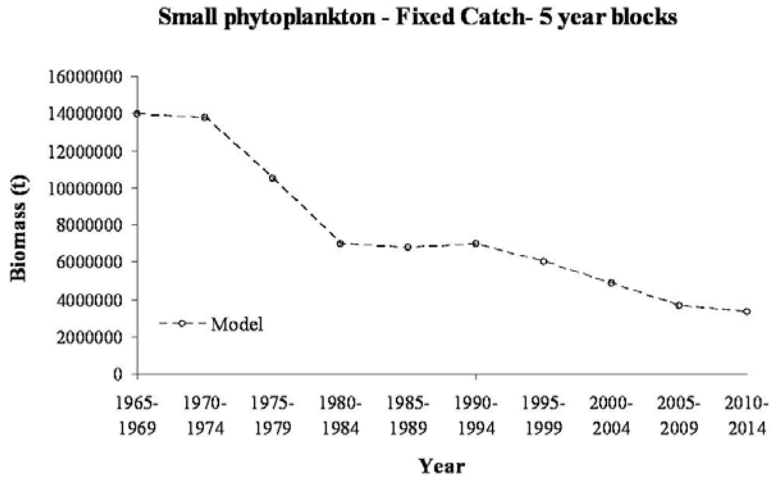


b.

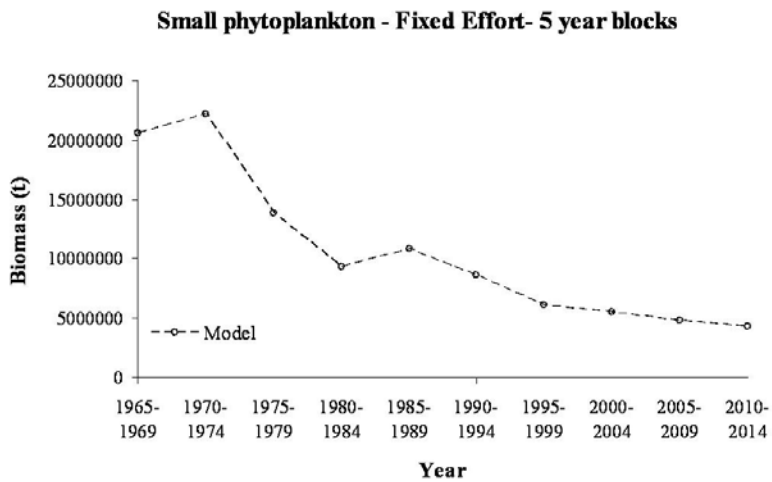


c.

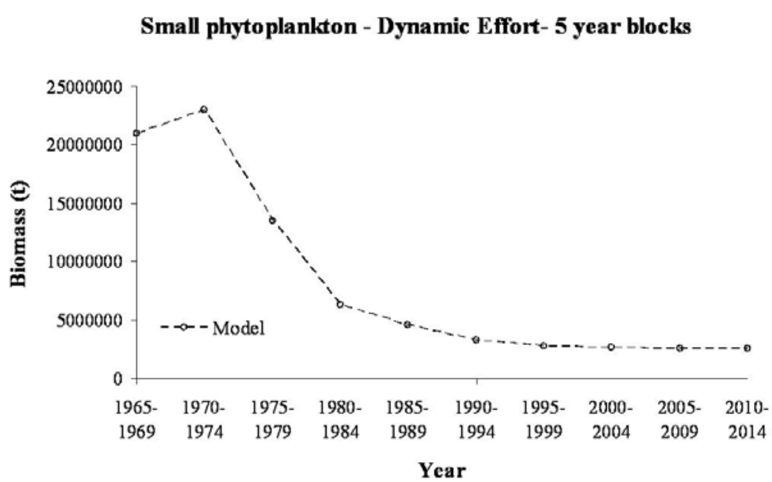
Figure B31. Large phytoplankton biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

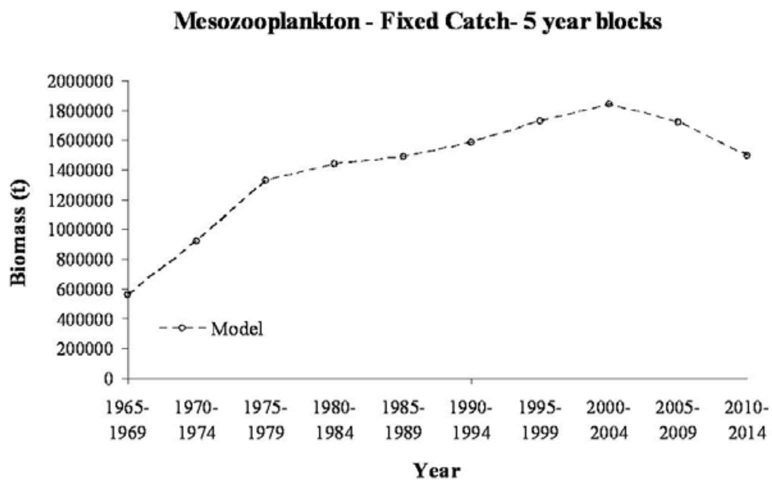


b.

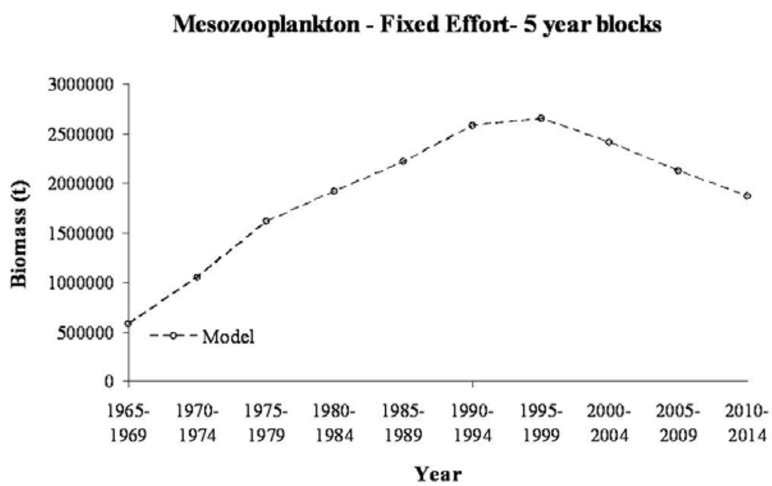


c.

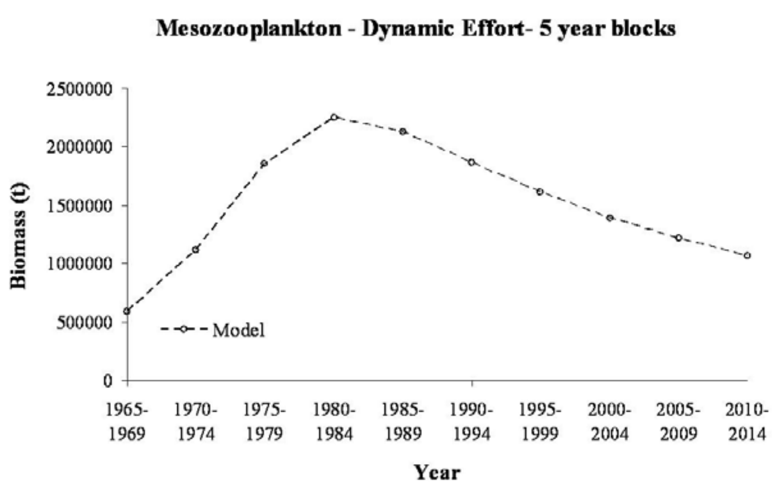
Figure B32. Small phytoplankton biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

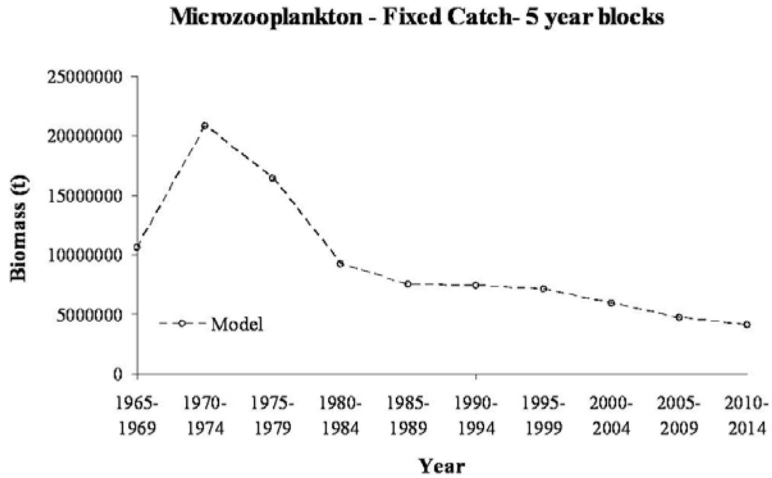


b.

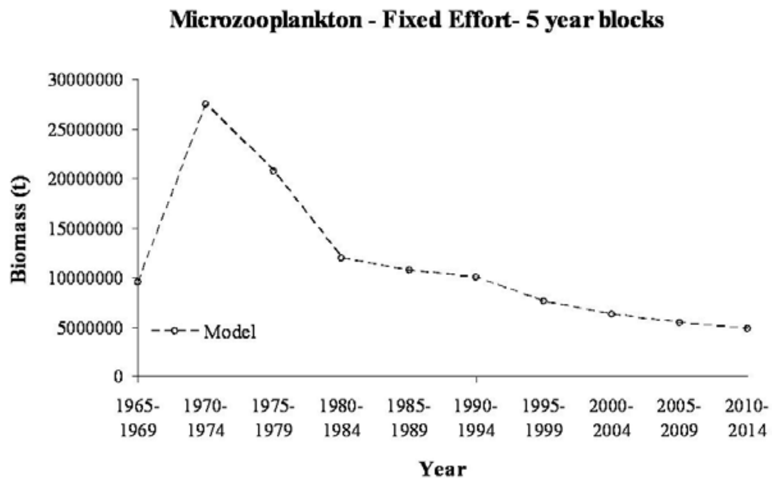


c.

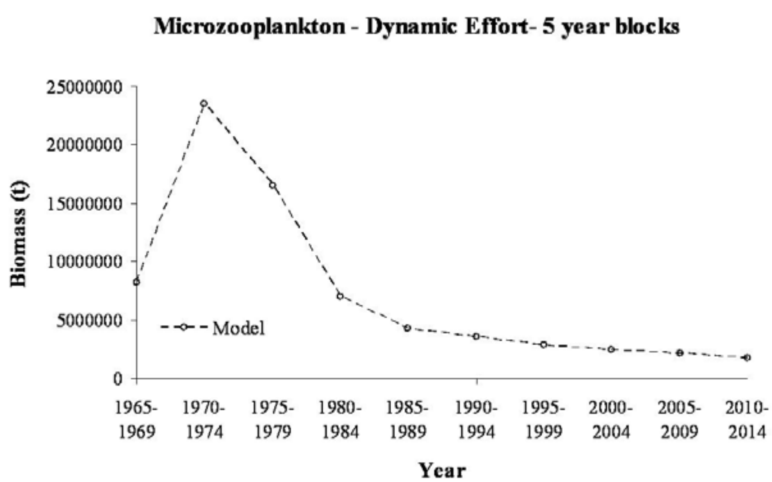
Figure B33. Mesozooplankton biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

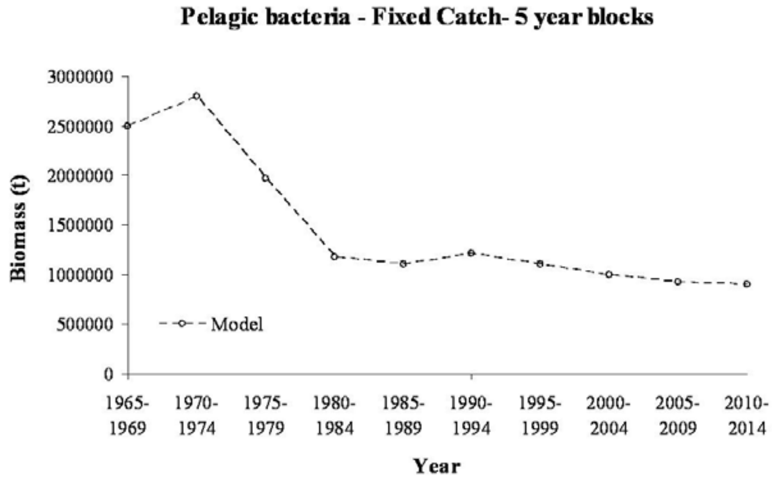


b.

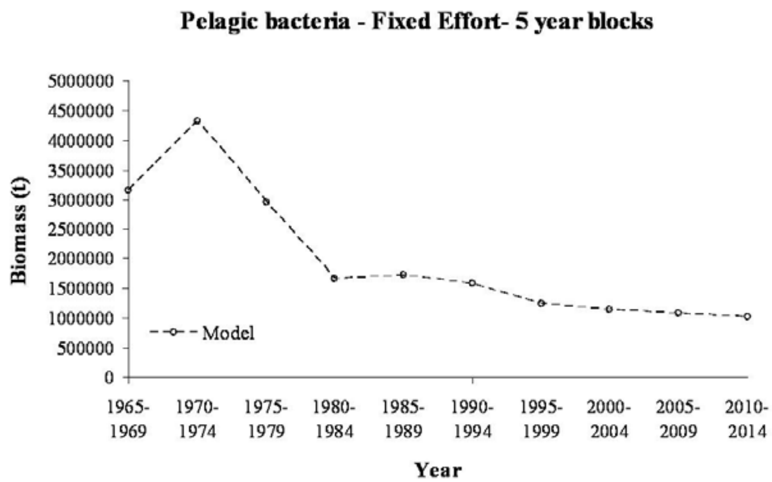


c.

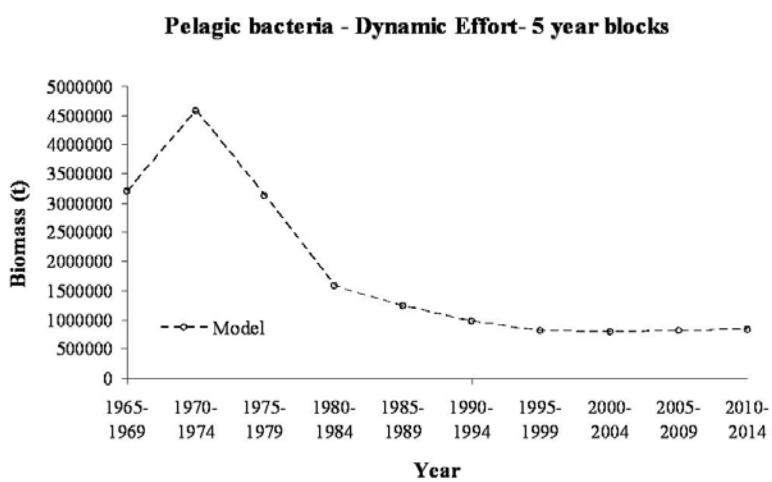
Figure B34. Microzooplankton biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

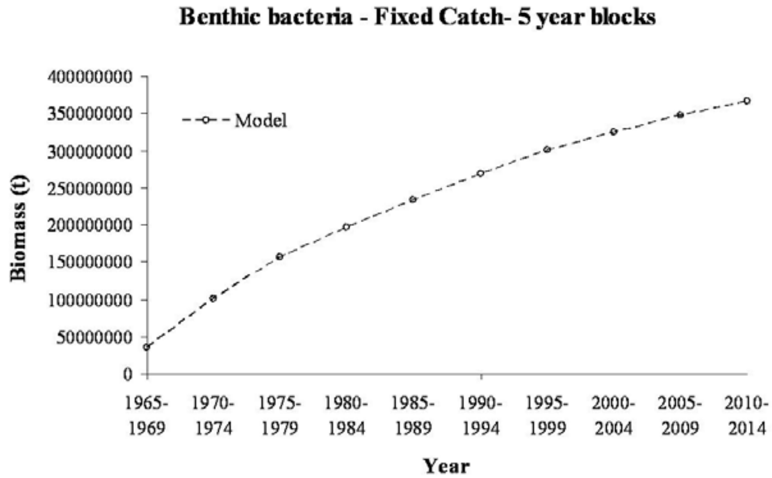


b.

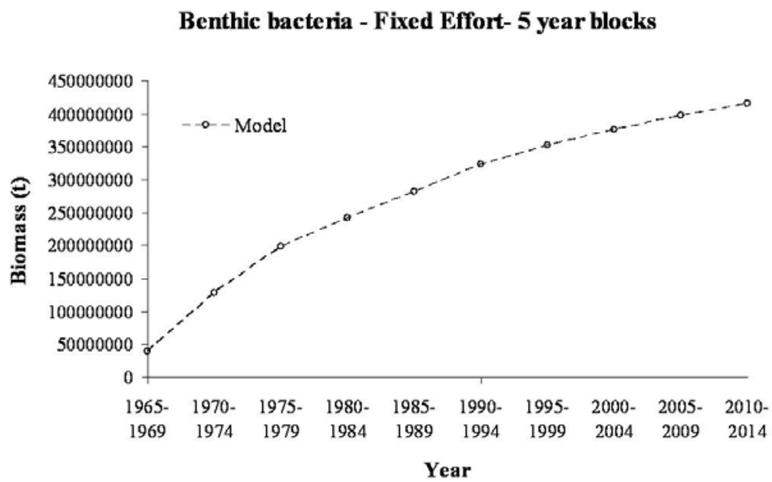


c.

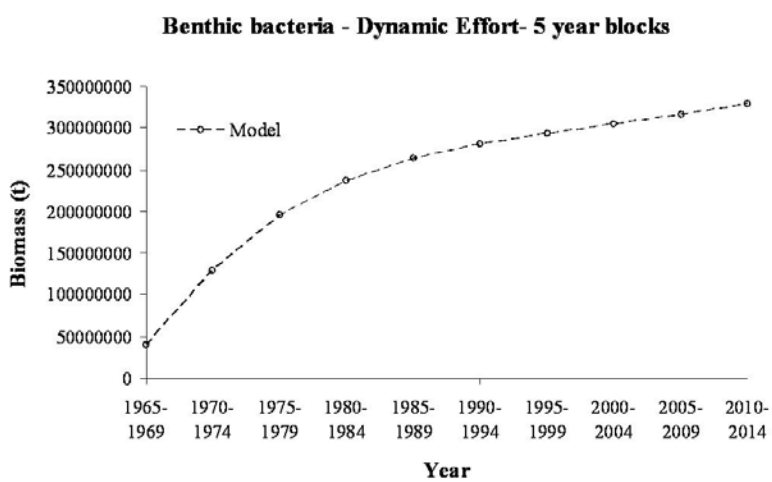
Figure B35. Pelagic bacteria biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

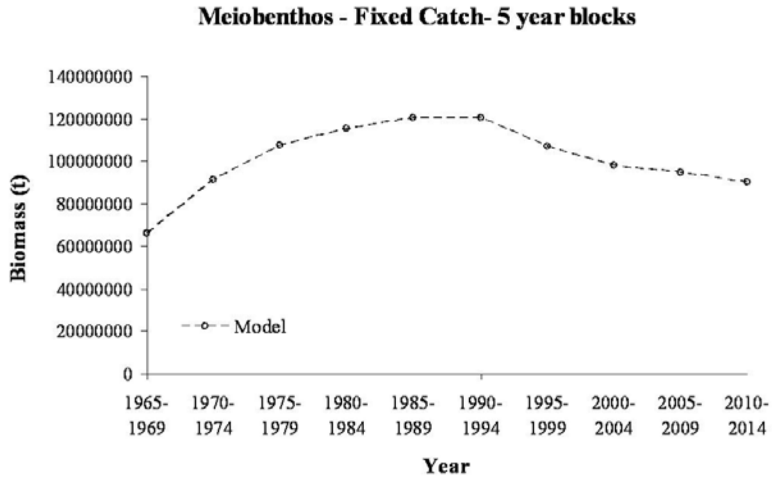


b.

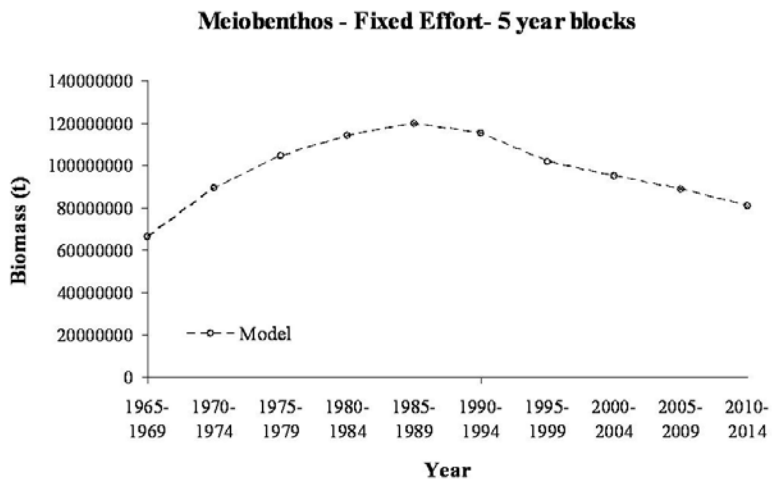


c.

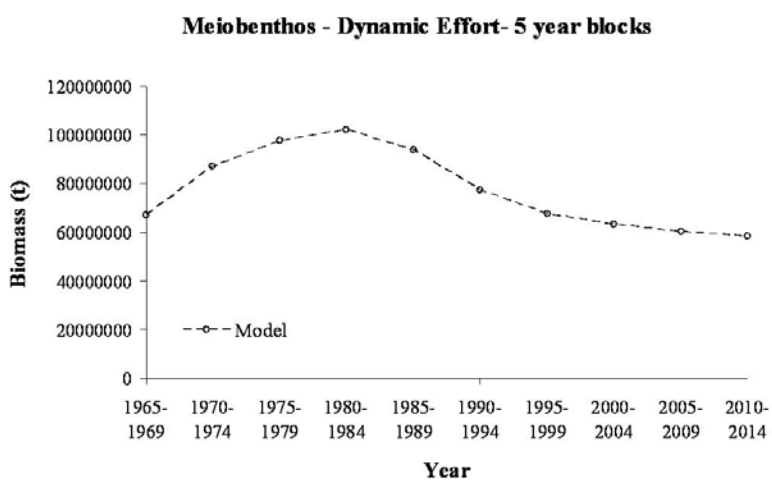
Figure B36. Benthic bacteria biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



a.

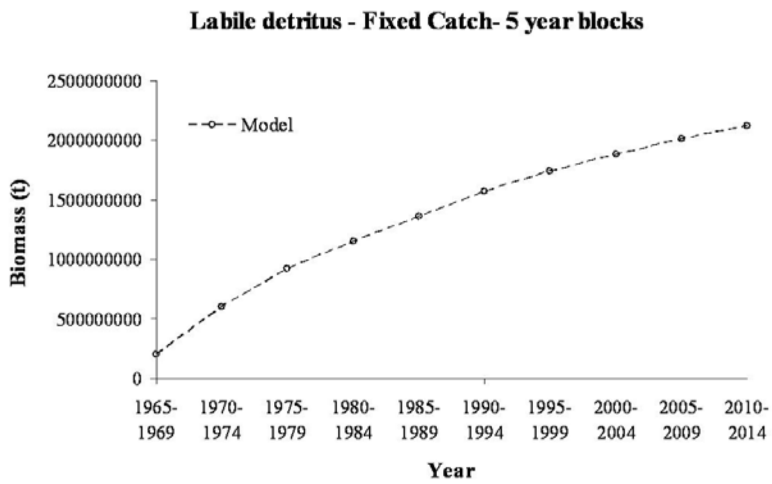


b.



c.

Figure B37. Meiobenthos biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



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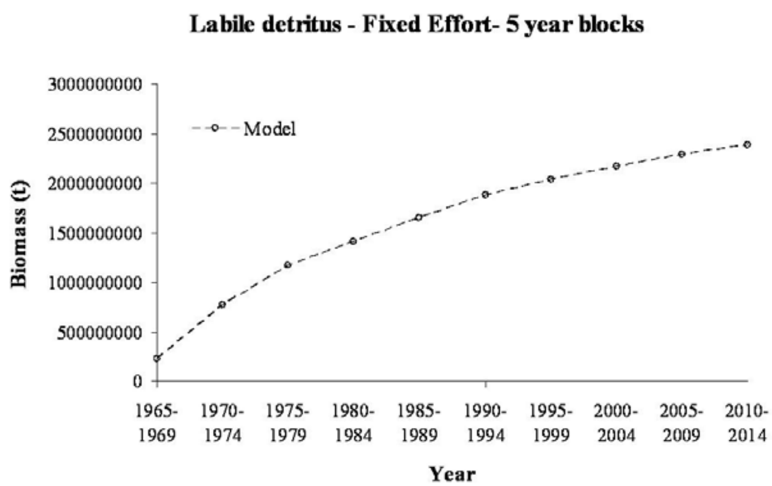

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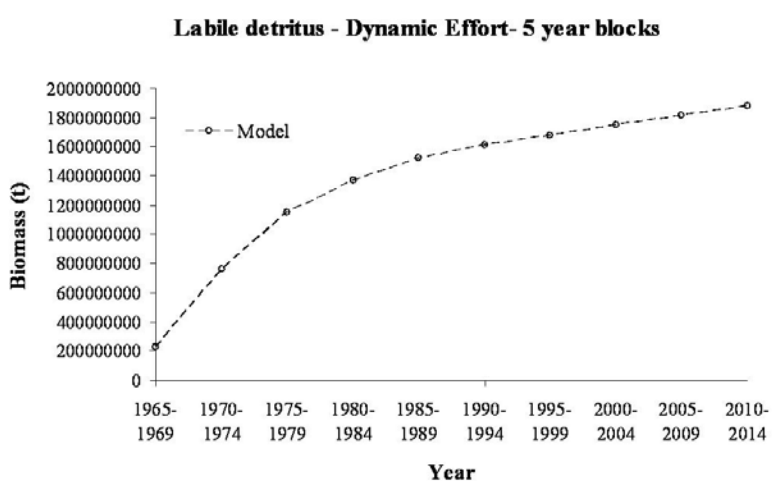
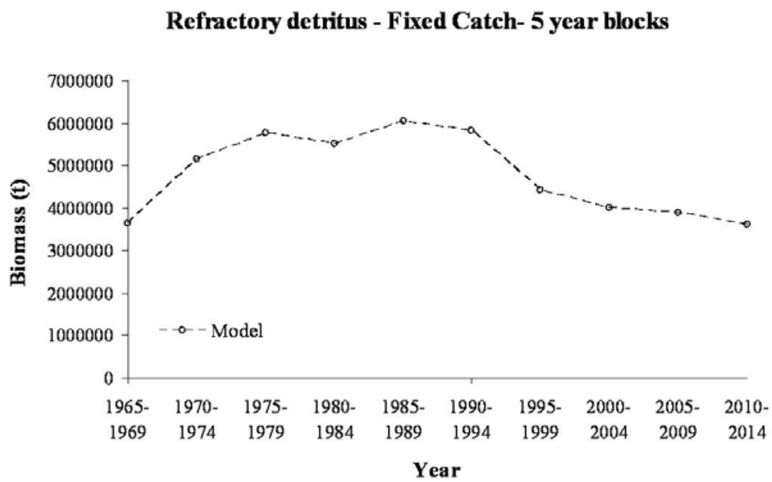


c.

Figure B38. Labile detritus biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



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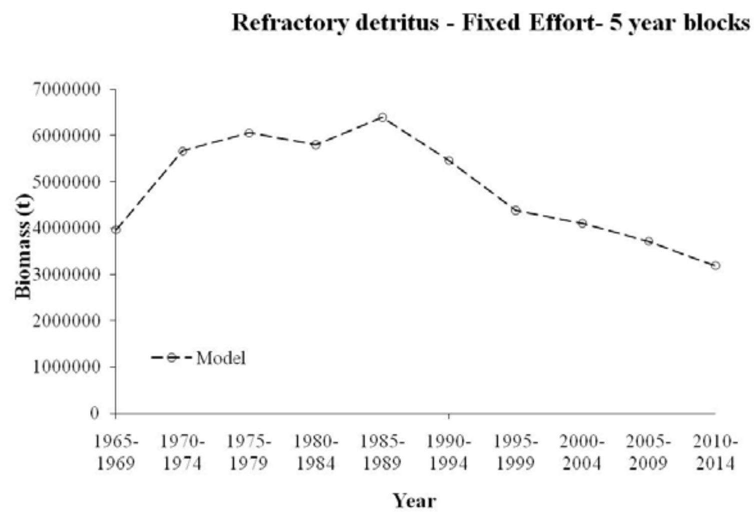

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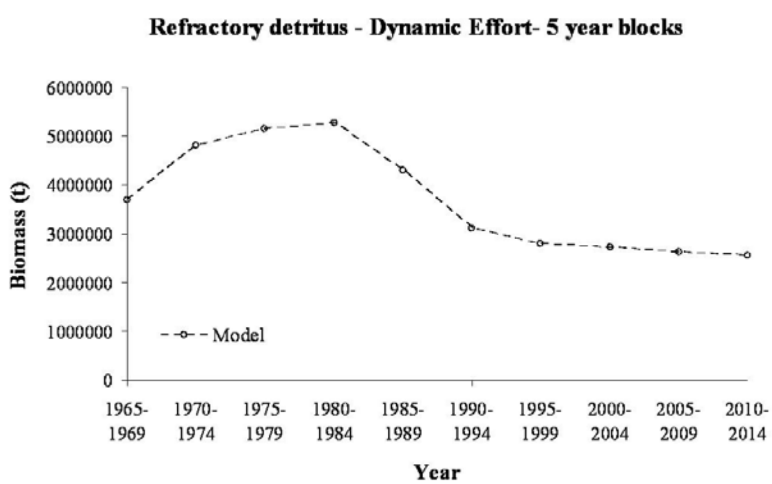
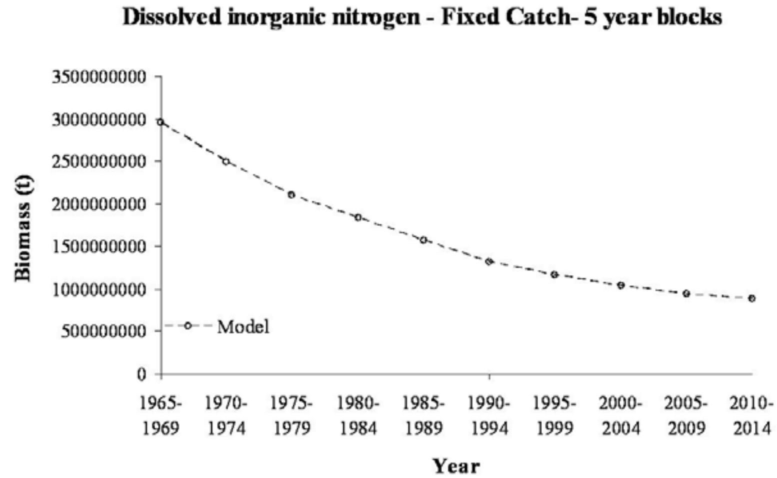


c.

Figure B39. Refractory detritus biomass trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.



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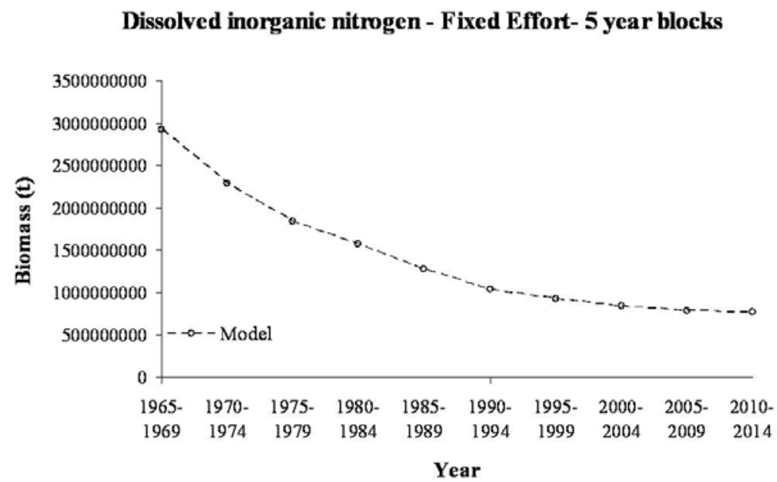

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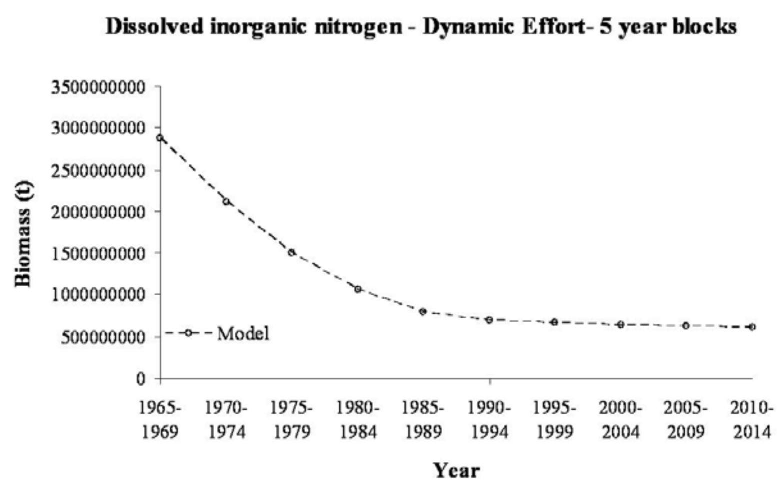
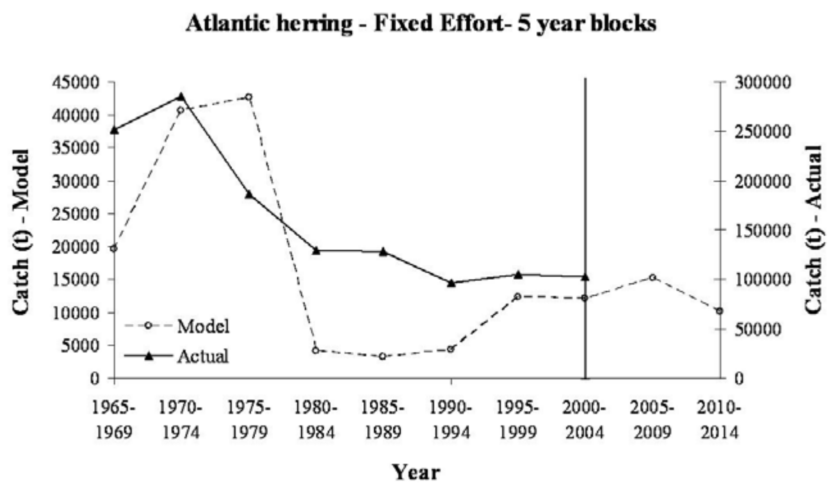


c.

Figure B40. Dissolved inorganic nitrogen trajectories for Atlantis NEUS (a. fixed catch run, b. fixed effort run, c. dynamic effort run). No observed time series were available.

APPENDIX C: Atlantis NEUS – CATCH TRAJECTORY RESULTS



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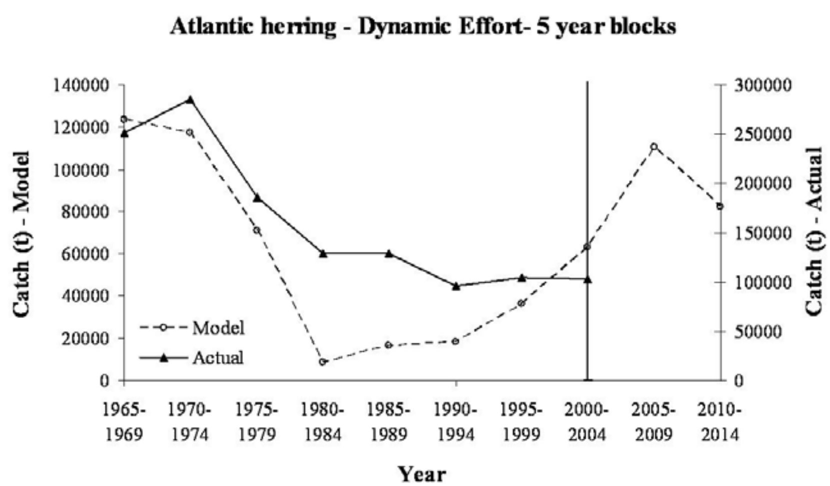
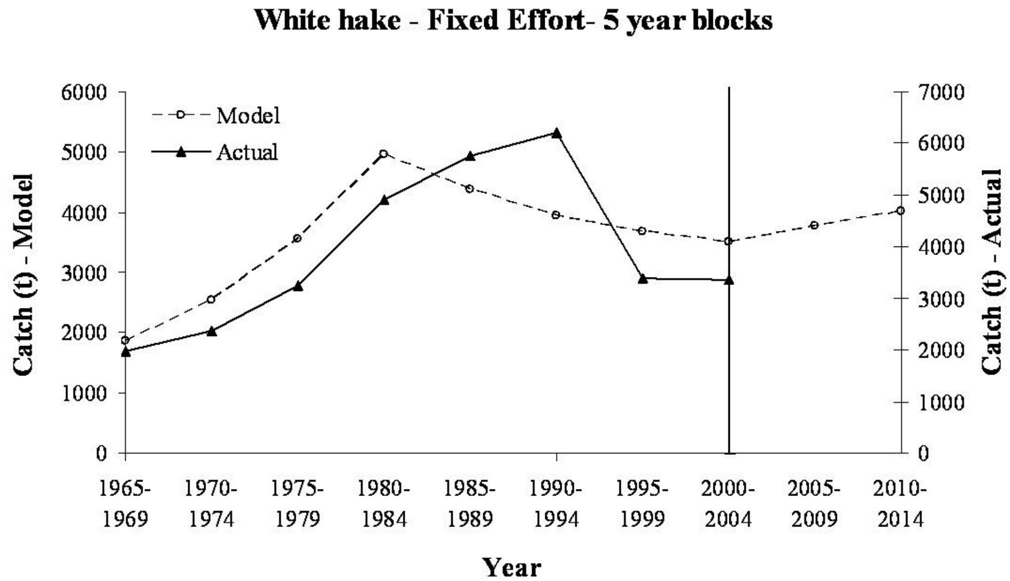


b.

Figure C1. Atlantic herring (*Clupea harengus*) catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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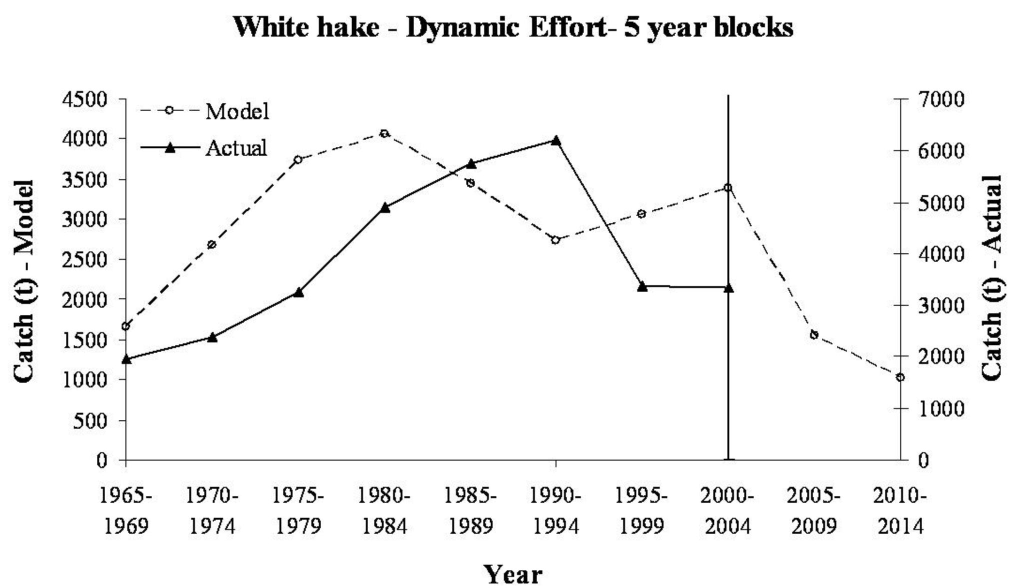
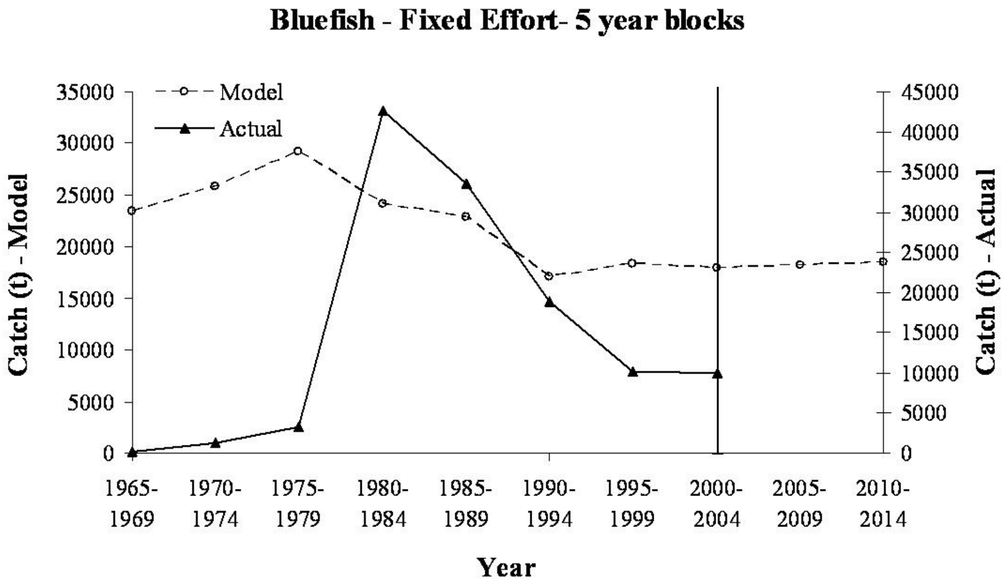


b.

Figure C2. White hake (*Urophycis tenuis*) catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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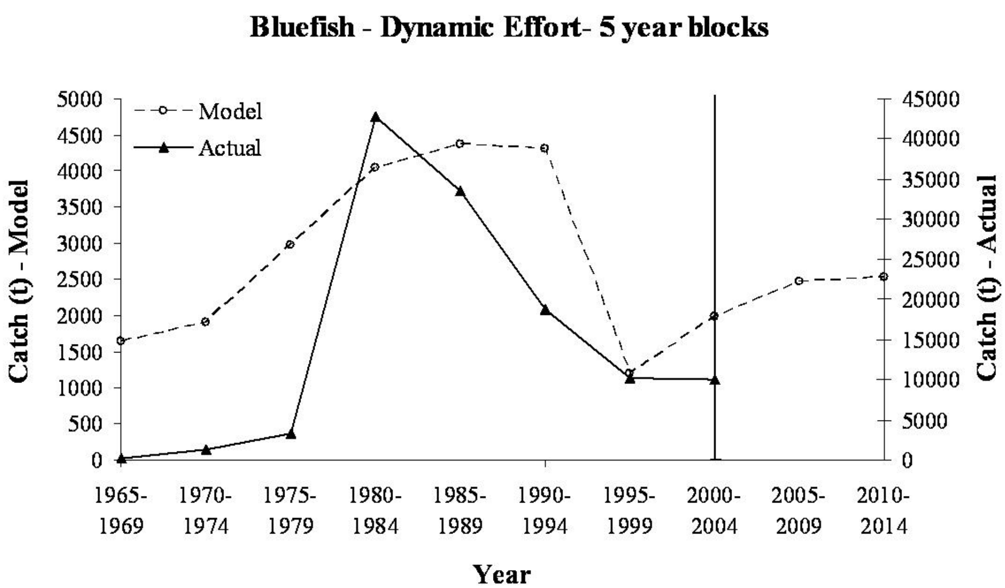
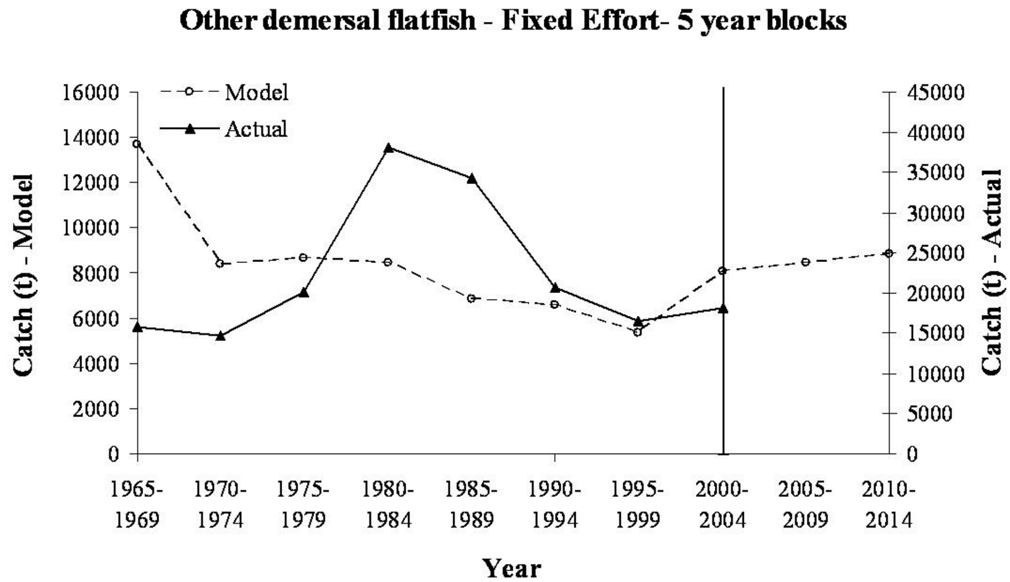


b.

Figure C3. Bluefish (*Pomatomus saltatrix*) catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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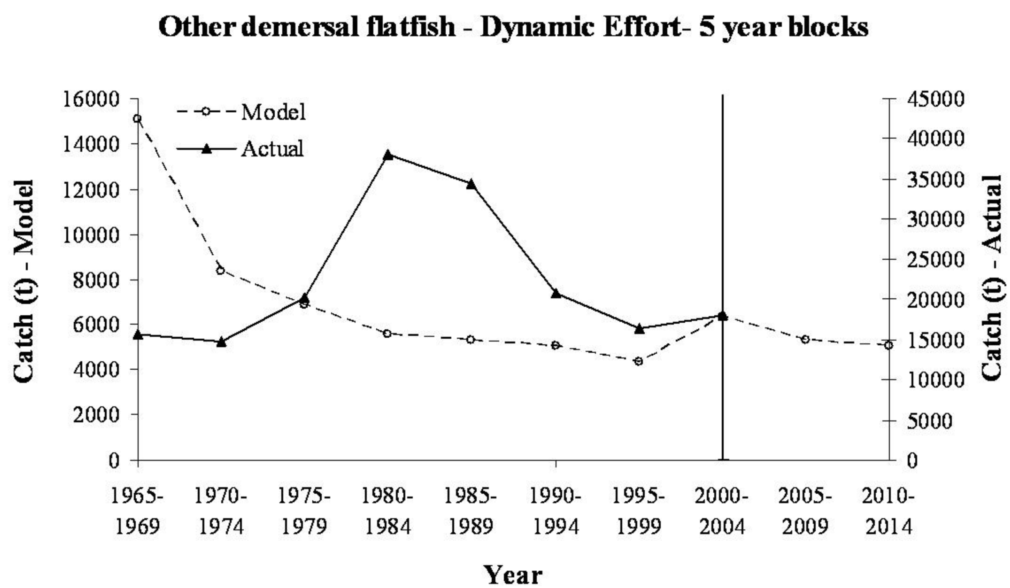
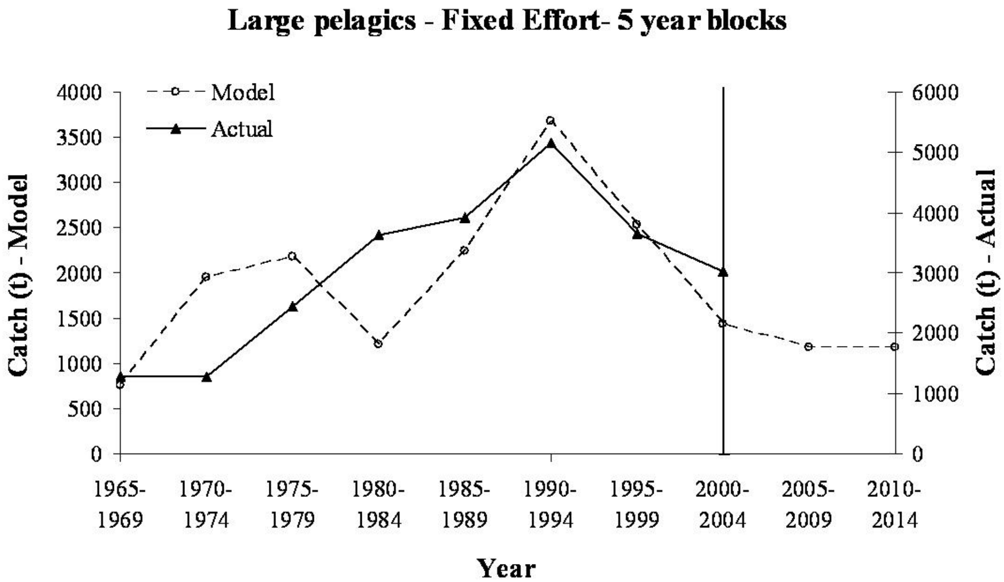


b.

Figure C4. Other demersal flatfish catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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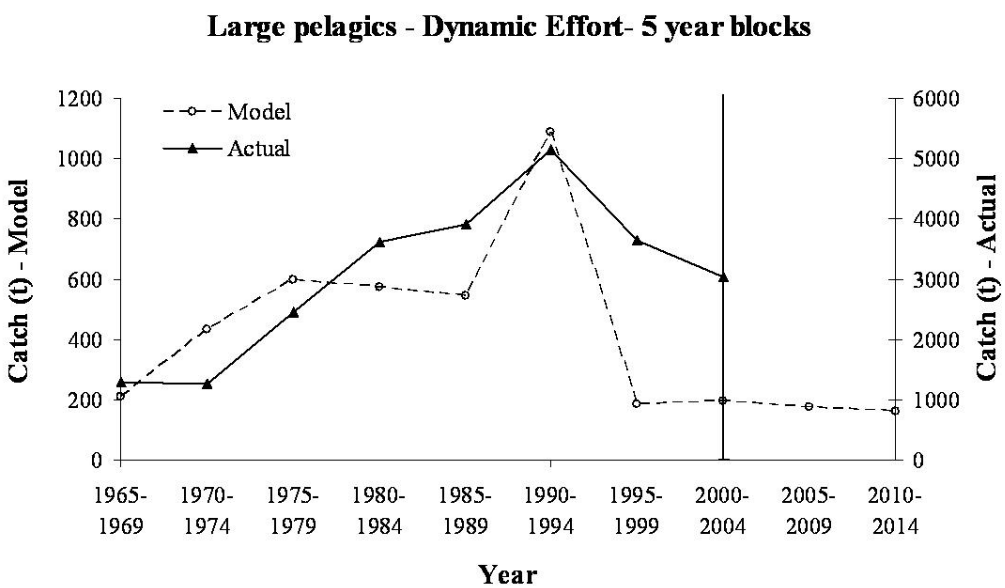
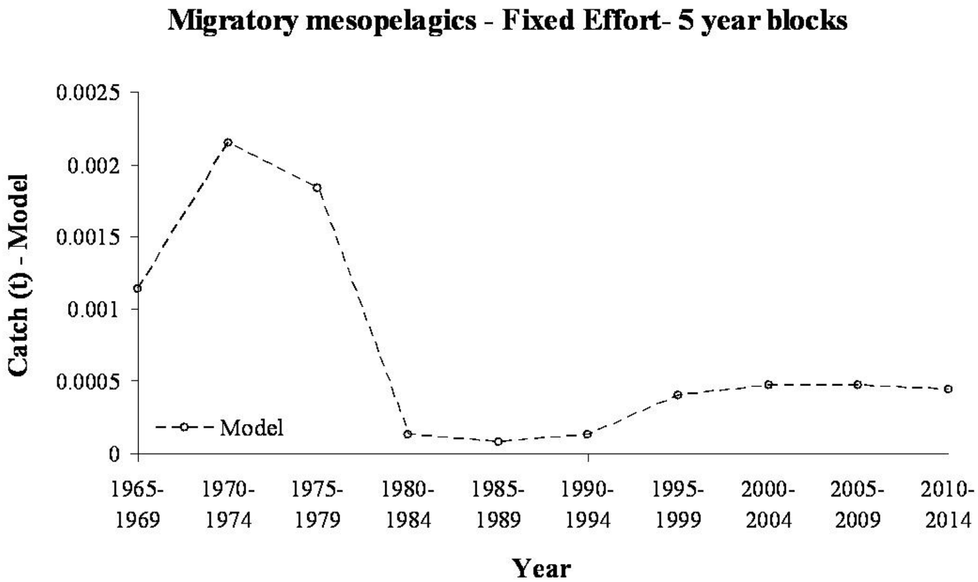
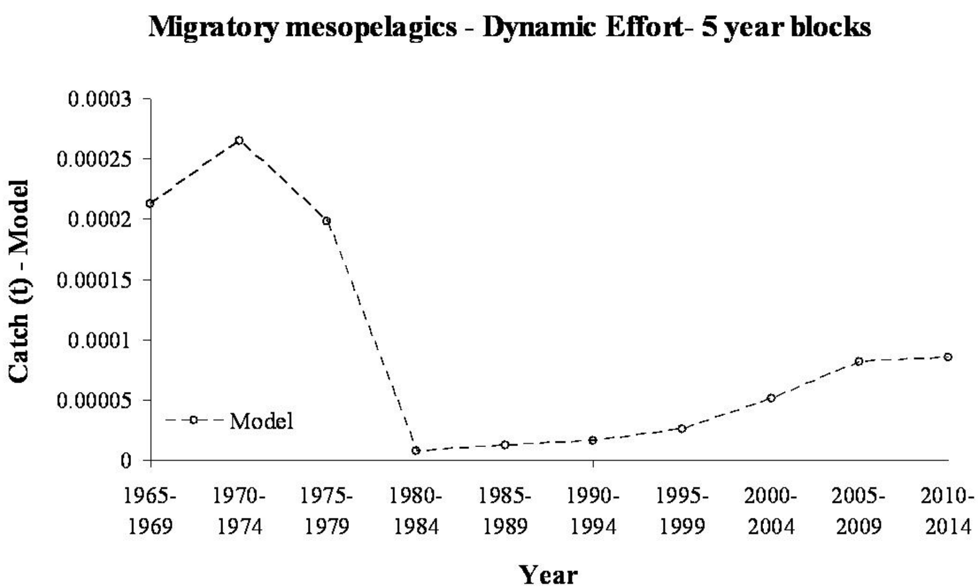


b.

Figure C5. Large pelagics catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.

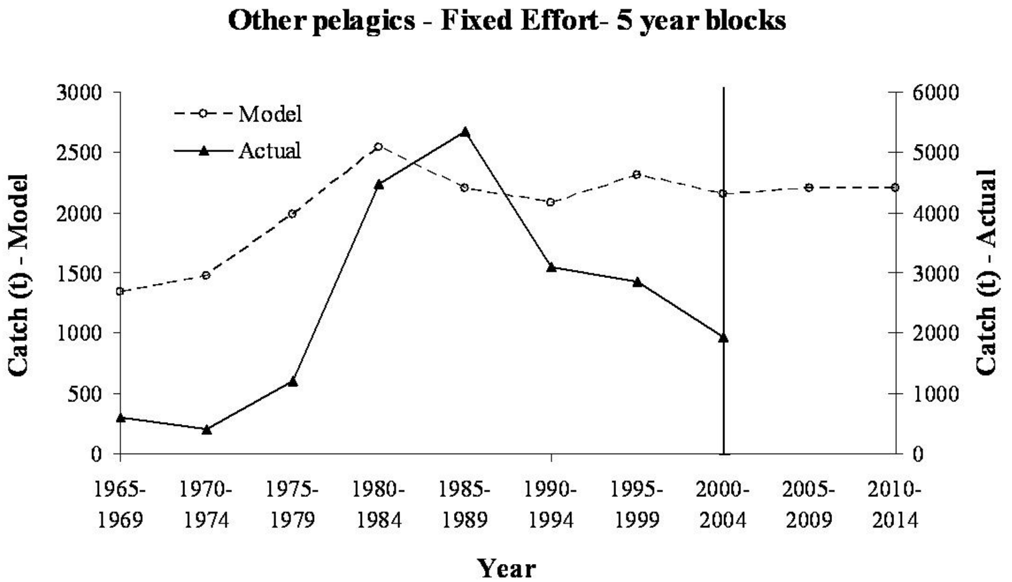


a.



b.

Figure C6. Migratory mesopelagics catch trajectories for Atlantis NEUS (a. fixed effort run, b. dynamic effort run). No observed time series was available.



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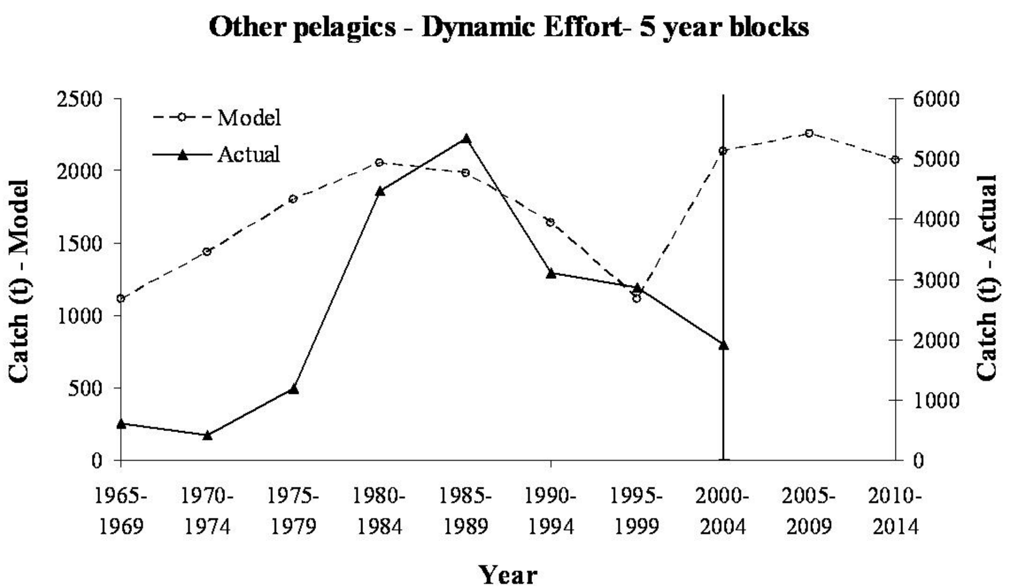
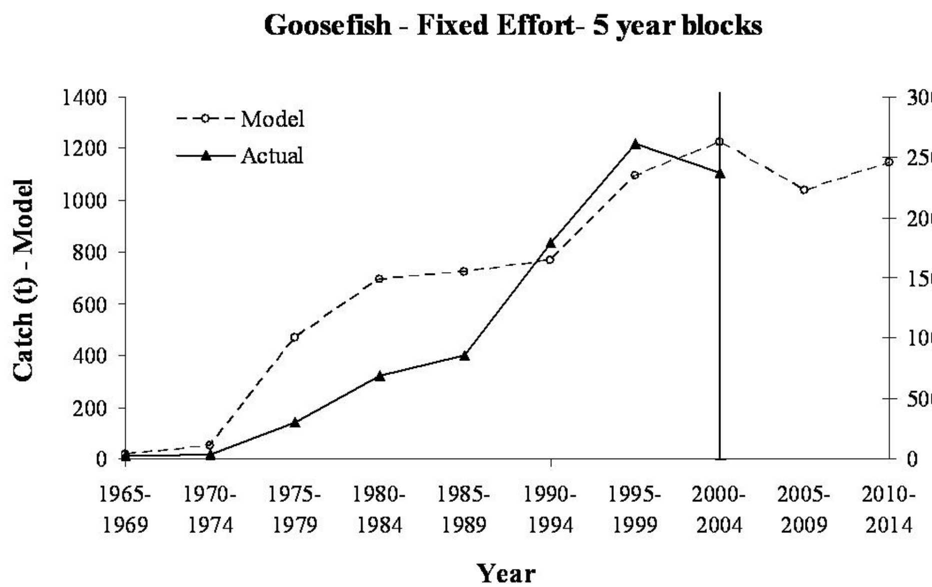
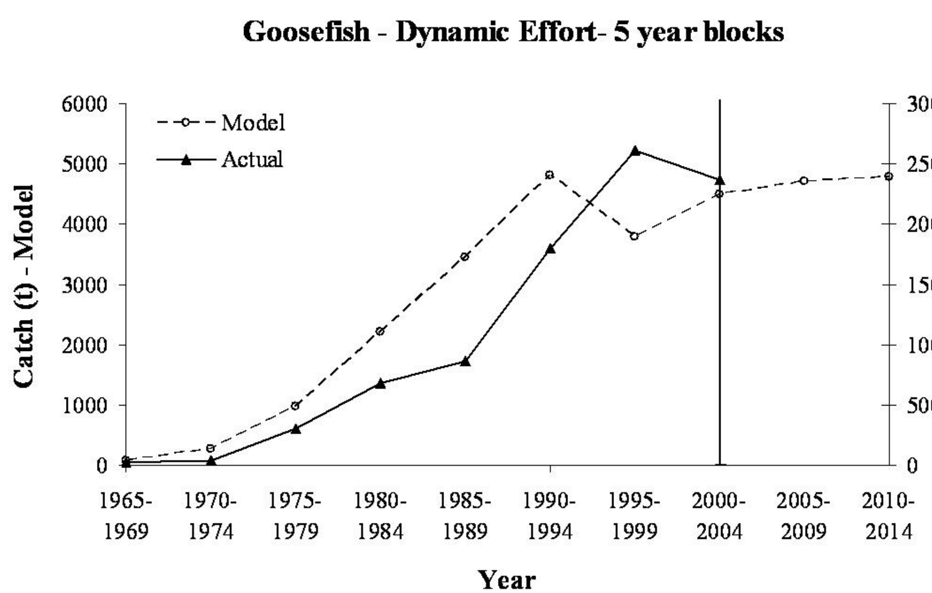


b.

Figure C7. Other pelagics catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.

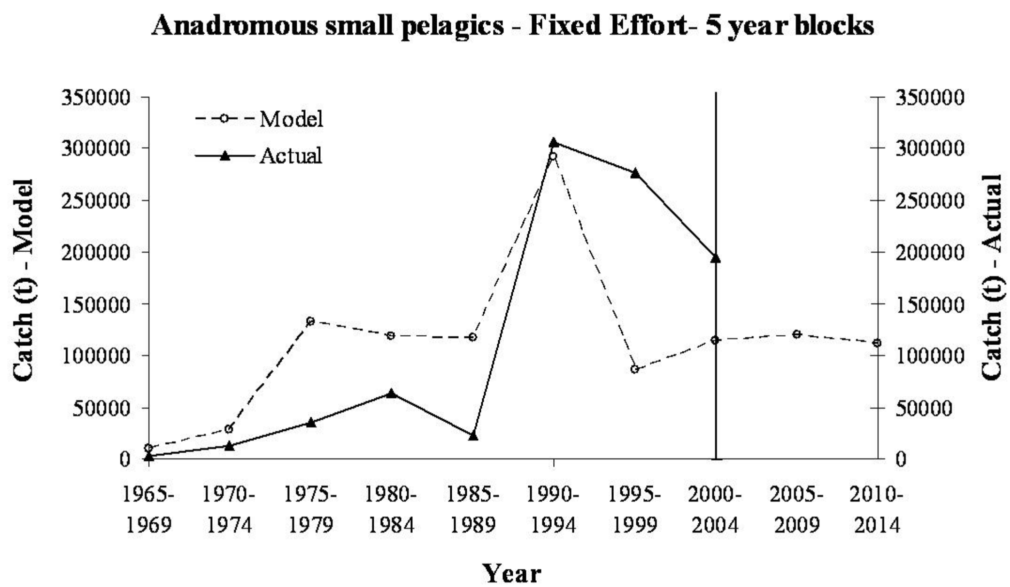


a.



b.

Figure C8. Goosefish (*Lophius americanus*) catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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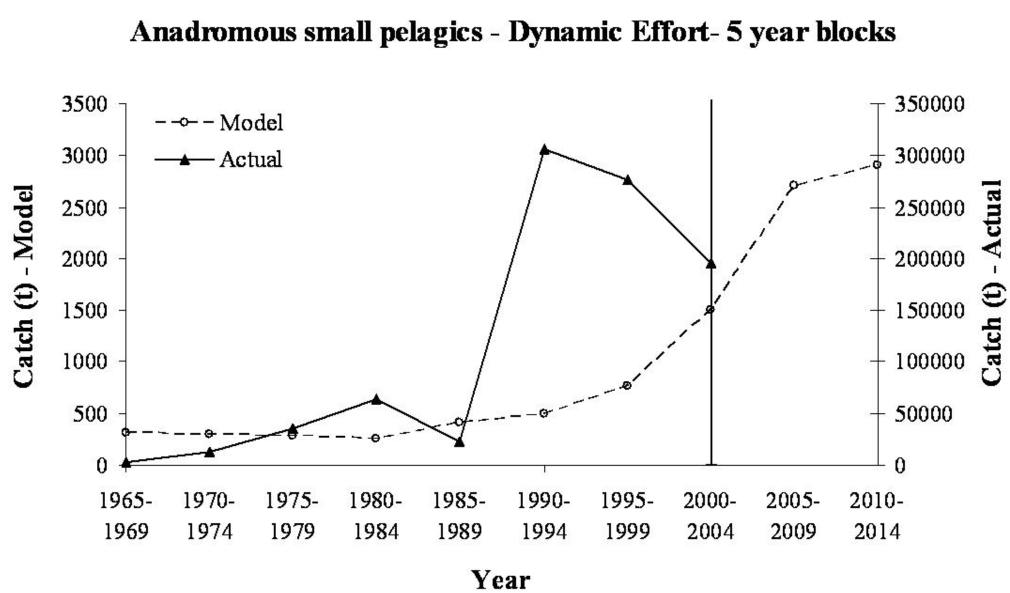
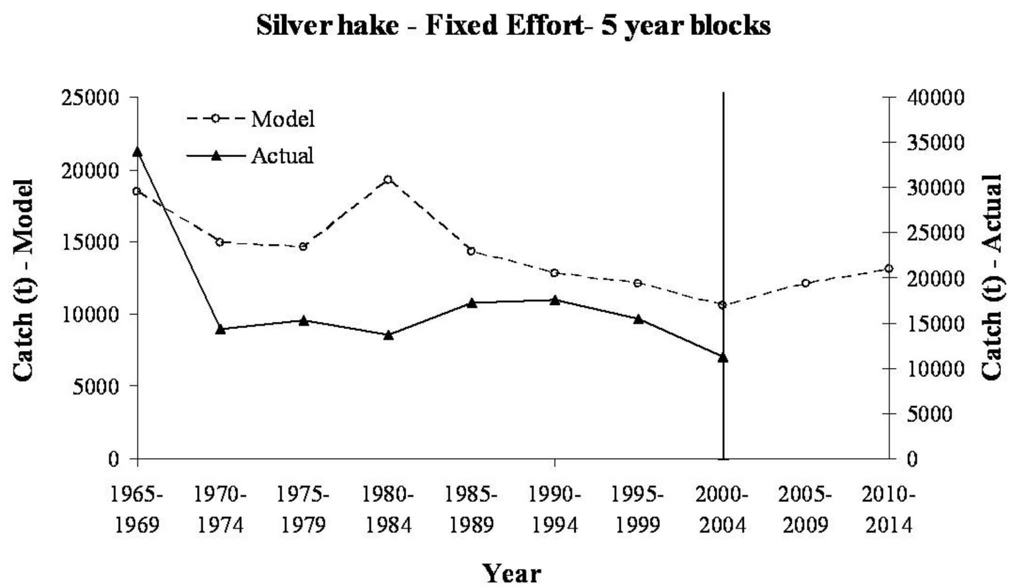


b.

Figure C9. Anadromous small pelagics catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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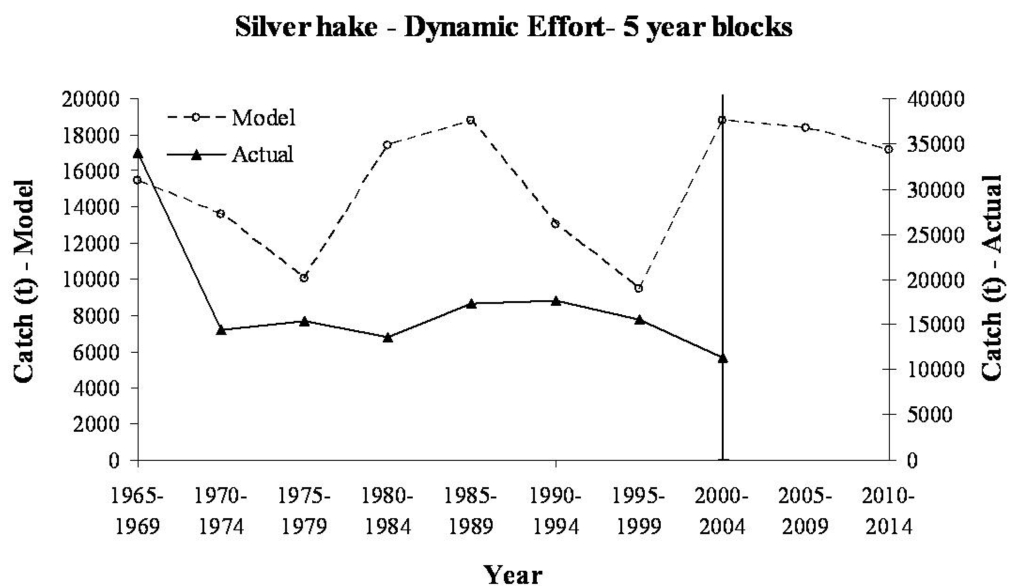
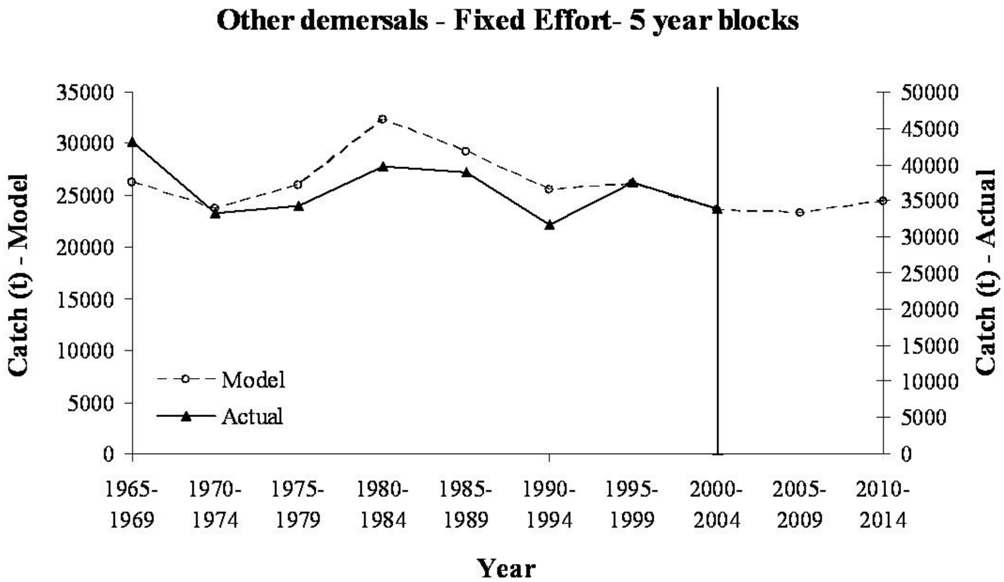


b.

Figure C10. Silver hake (*Merluccius bilinearis*) catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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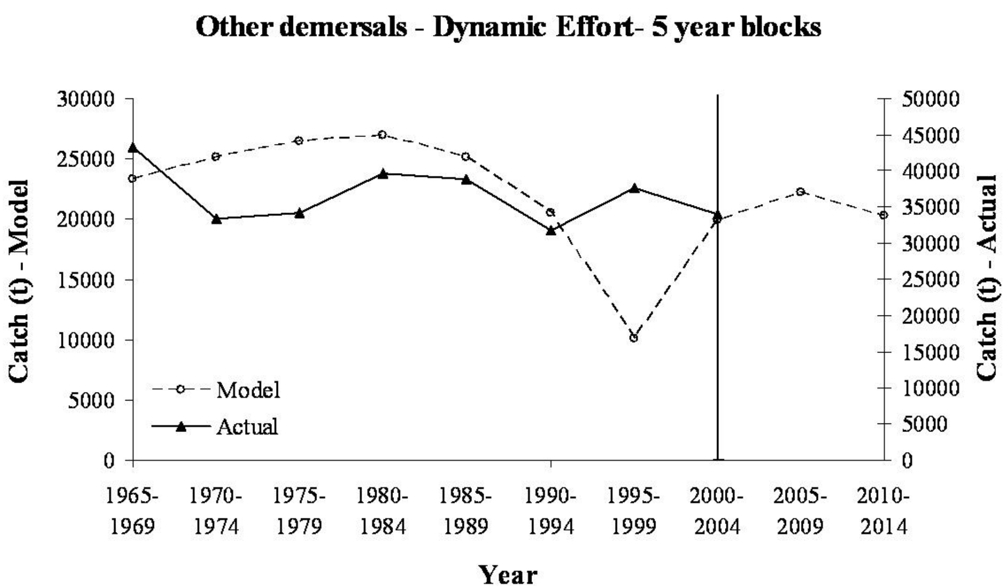
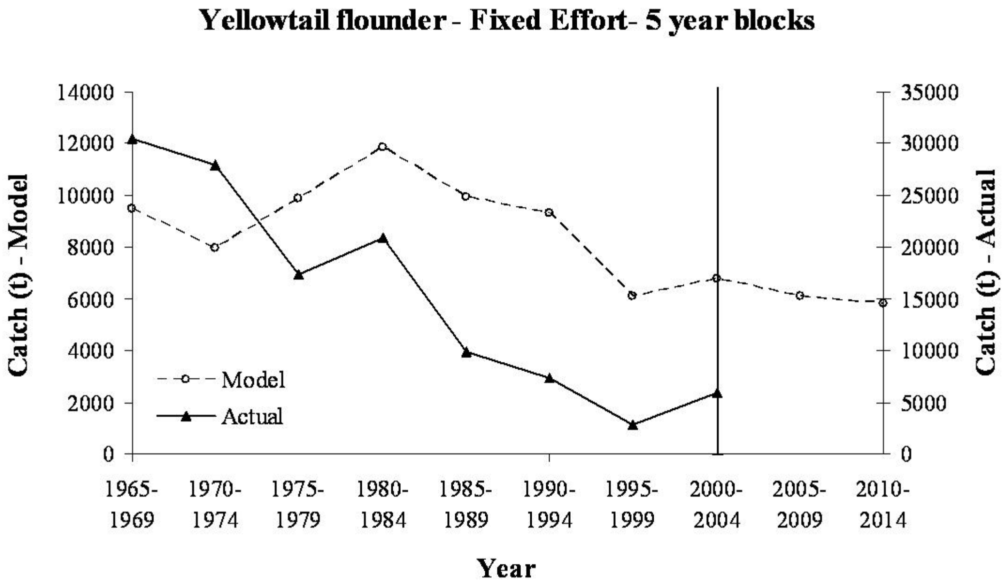


b.

Figure C11. Other demersals catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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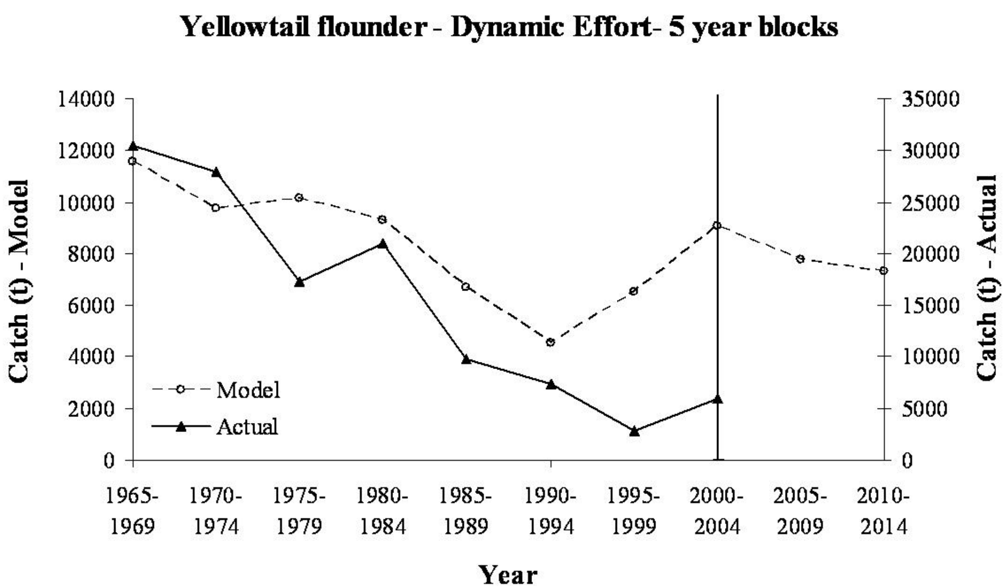
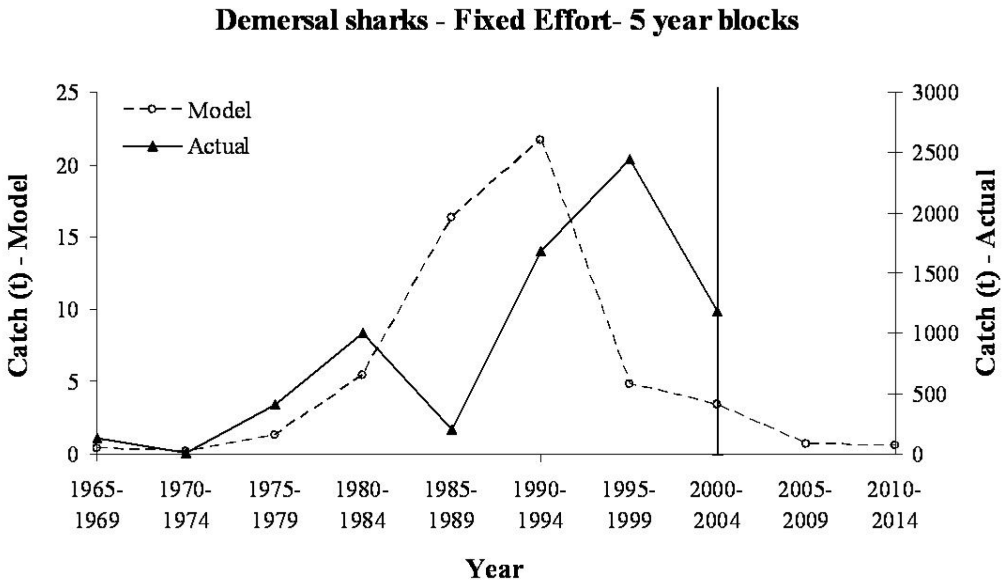


b.

Figure C12. Yellowtail flounder (*Limanda ferruginea*) catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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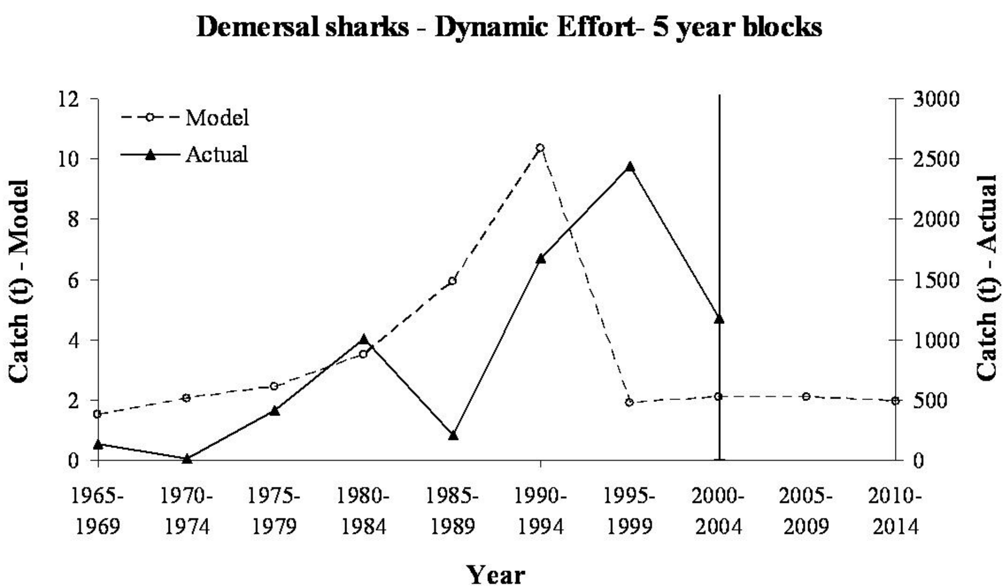
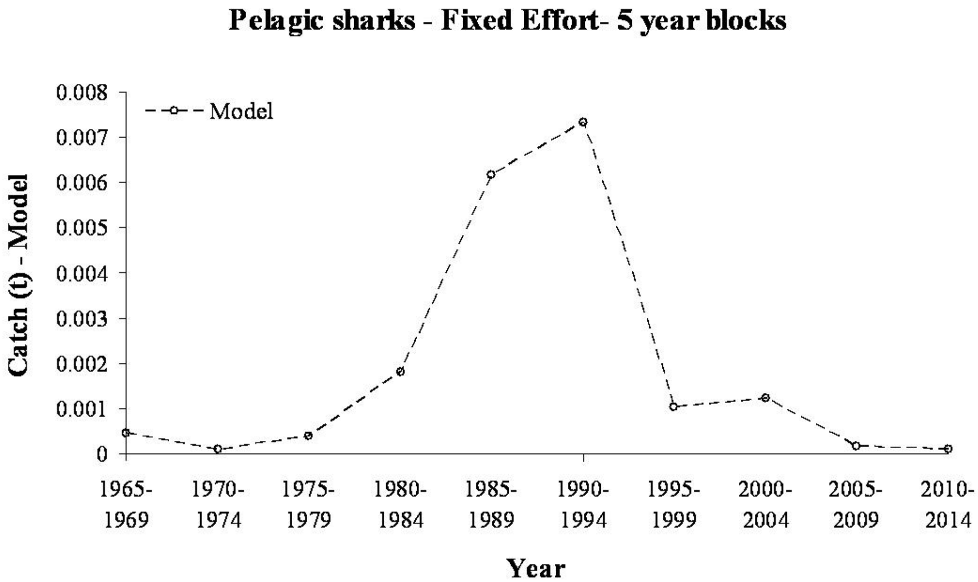
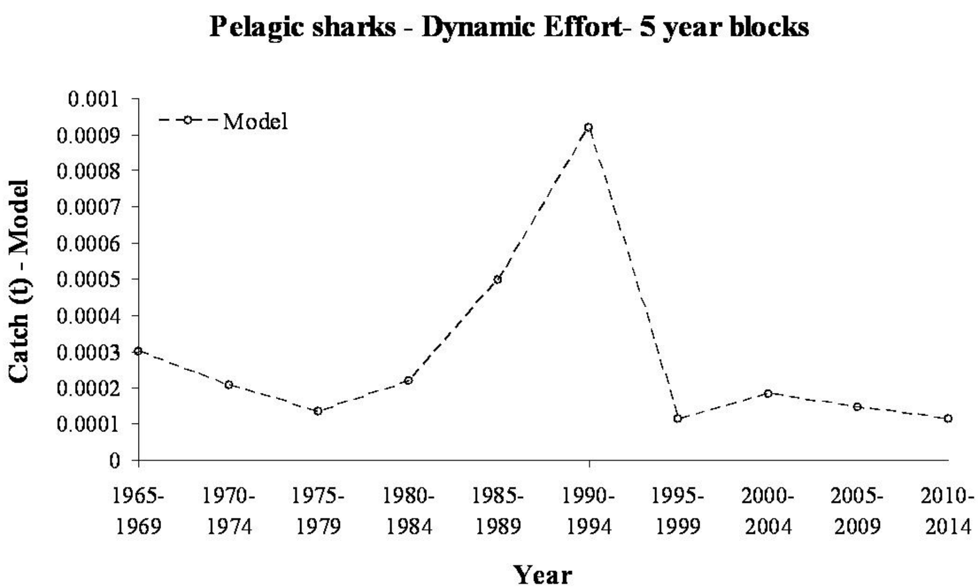


b.

Figure C13. Demersal sharks catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.

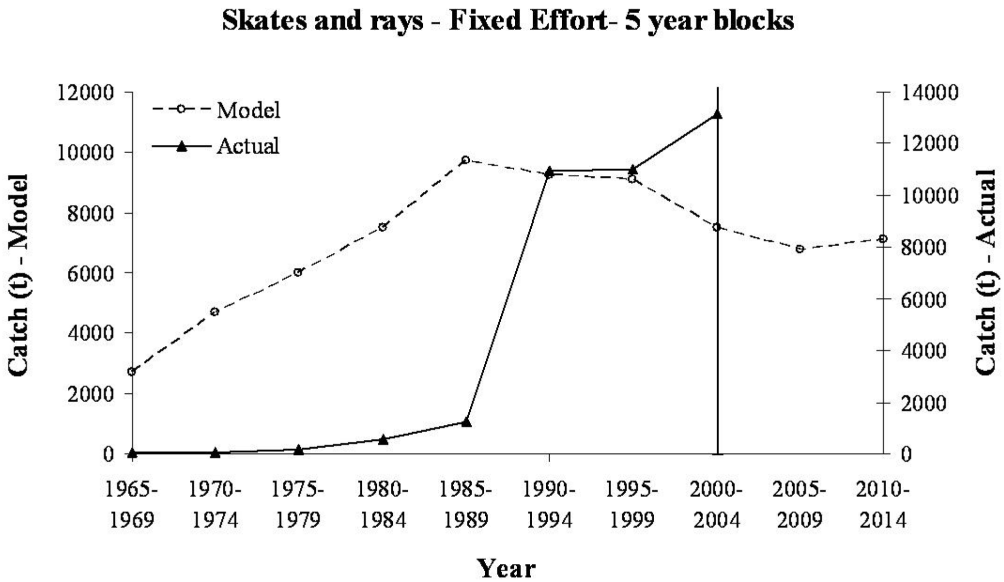


a.



b.

Figure C14. Pelagic sharks catch trajectories for Atlantis NEUS (a. fixed effort run, b. dynamic effort run). No observed time series was available.



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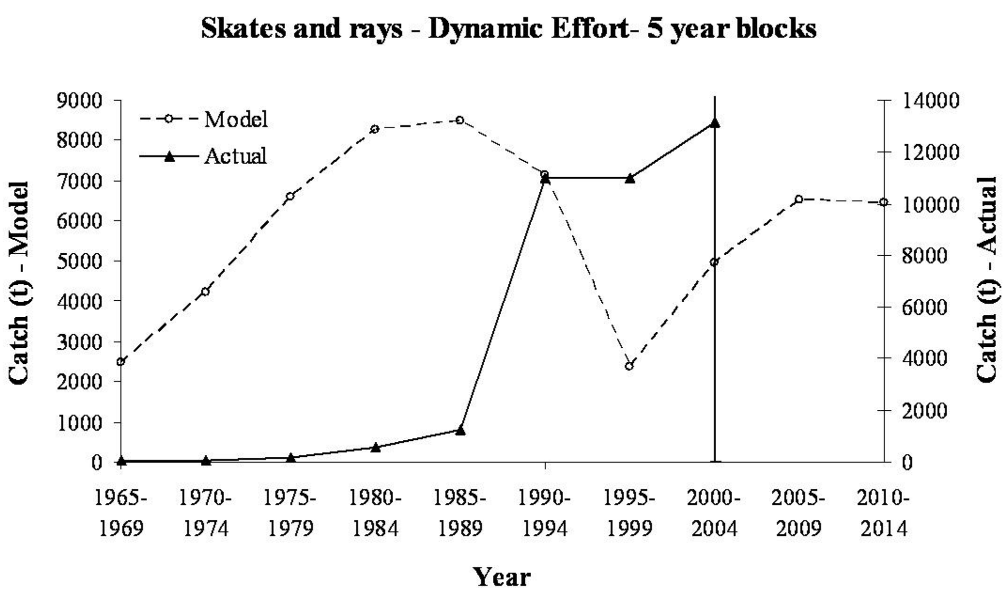
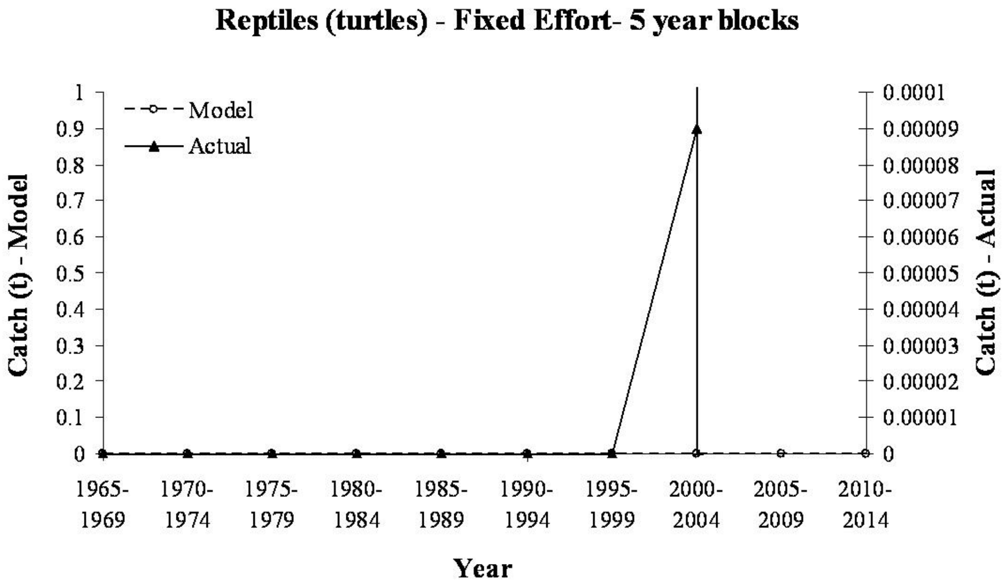


b.

Figure C15. Skates and rays catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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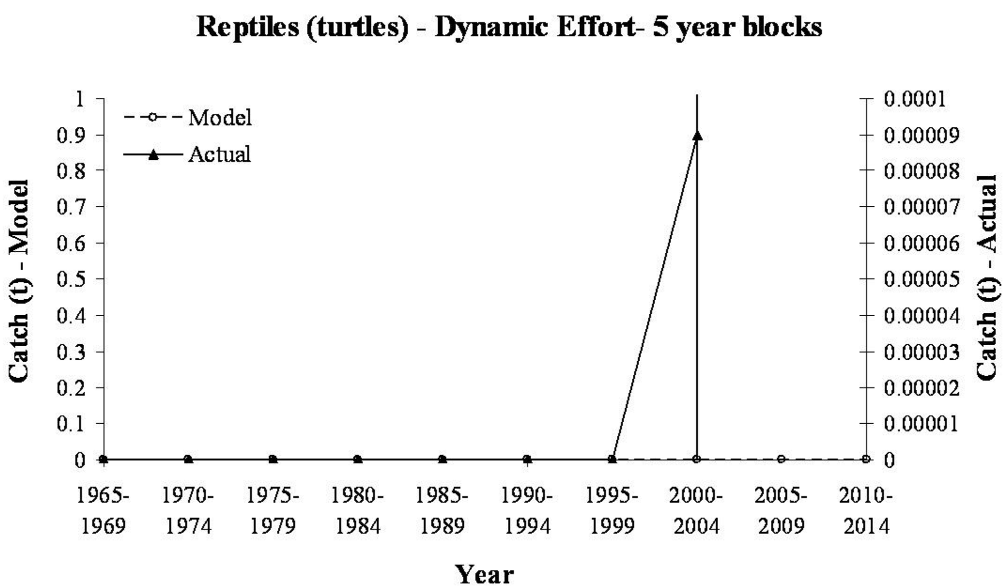
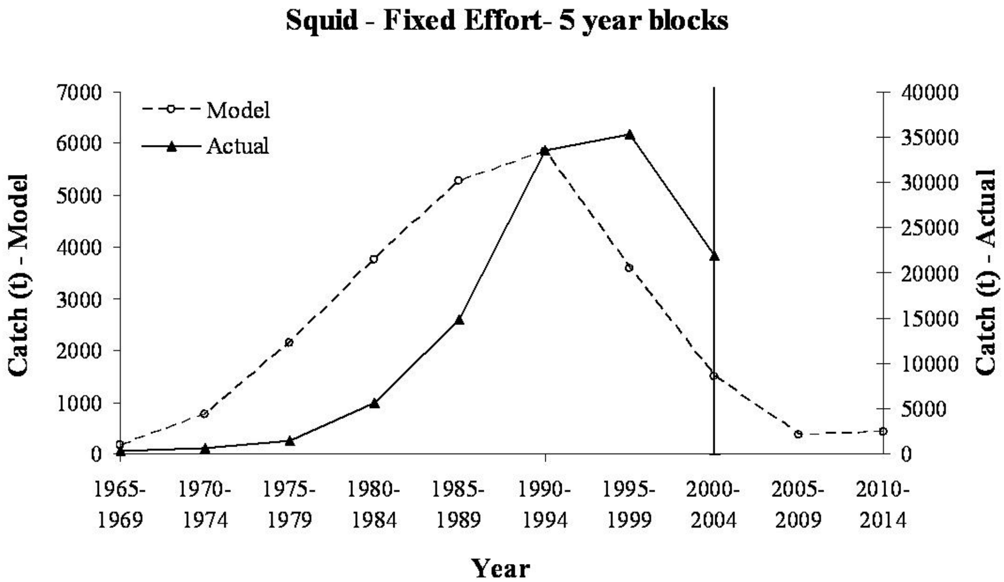


b.

Figure C16. Reptiles catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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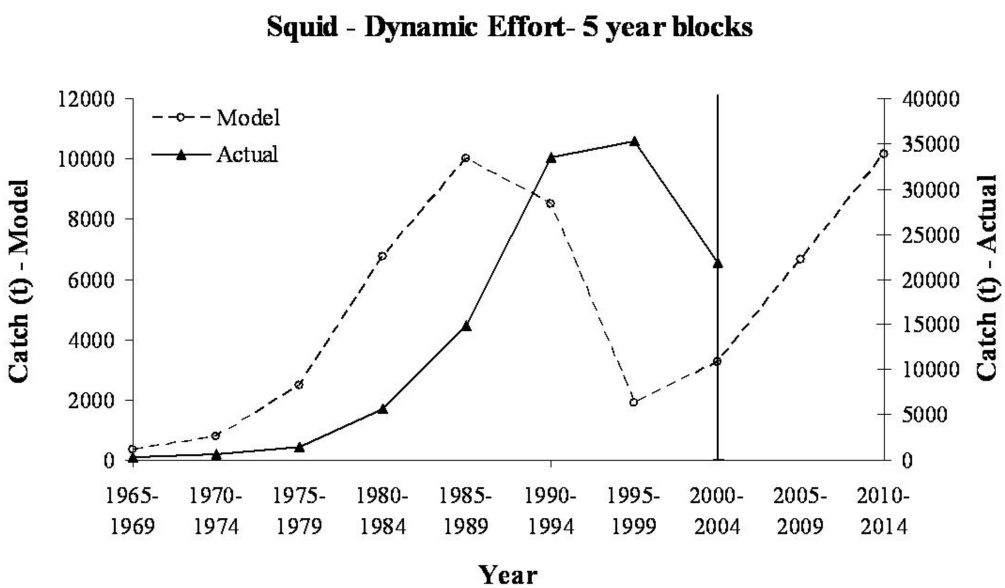
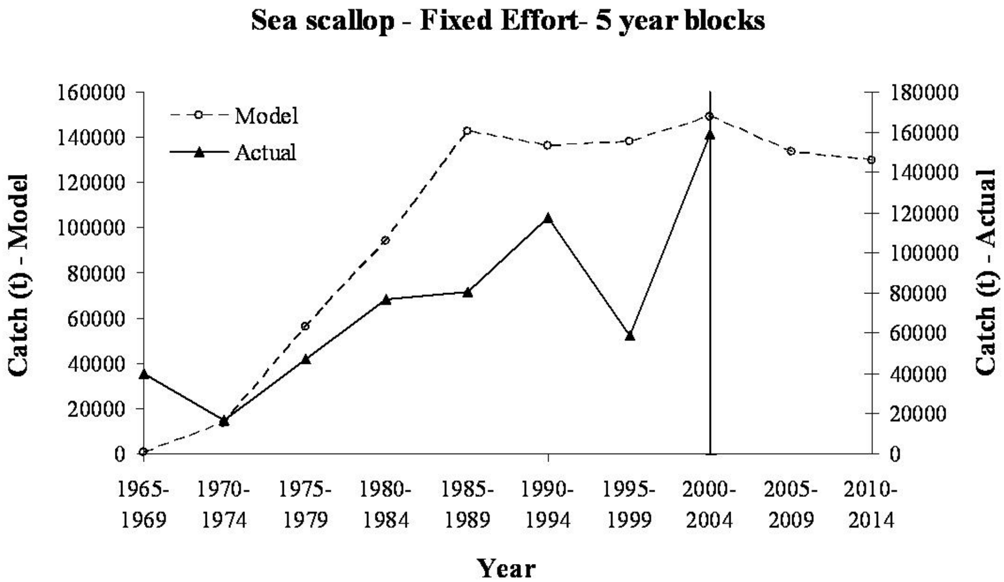


b.

Figure C17. Squid catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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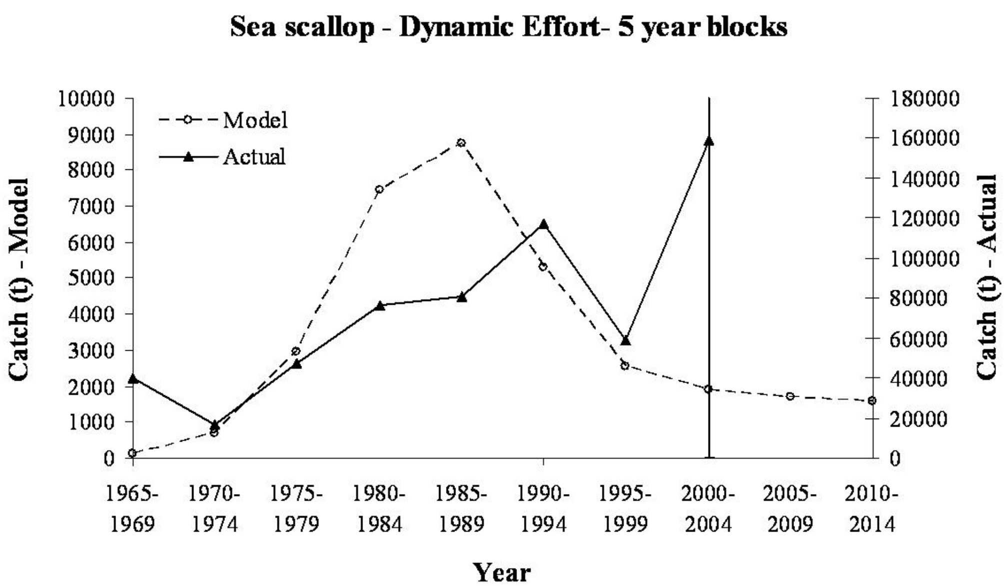
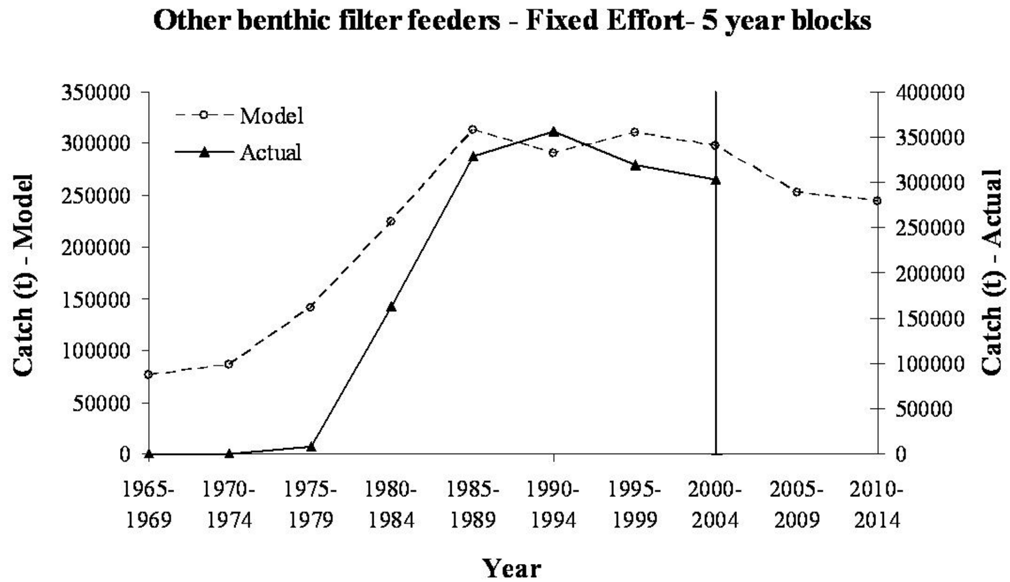


b.

Figure C18. Sea scallop (*Placopecten magellanicus*) catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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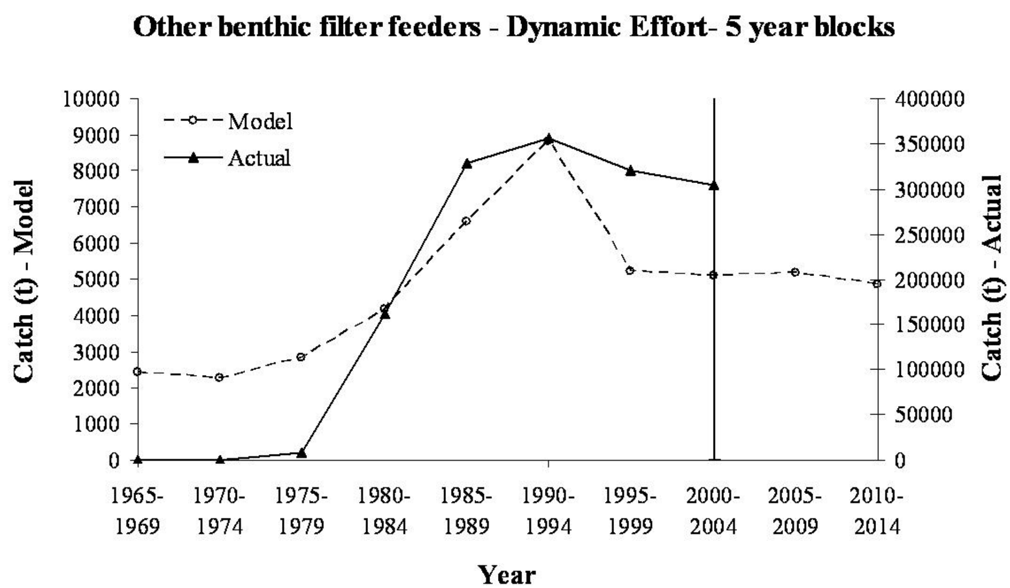
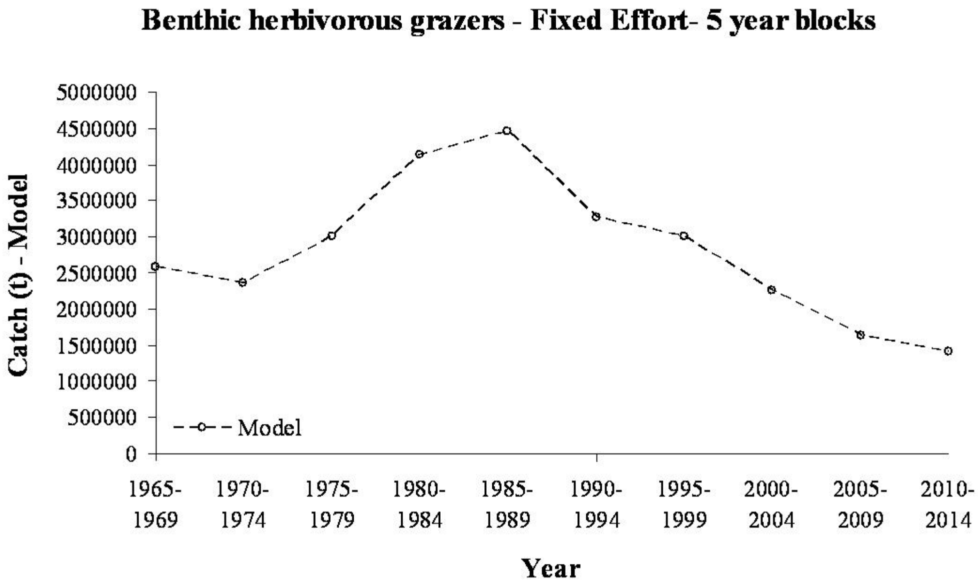
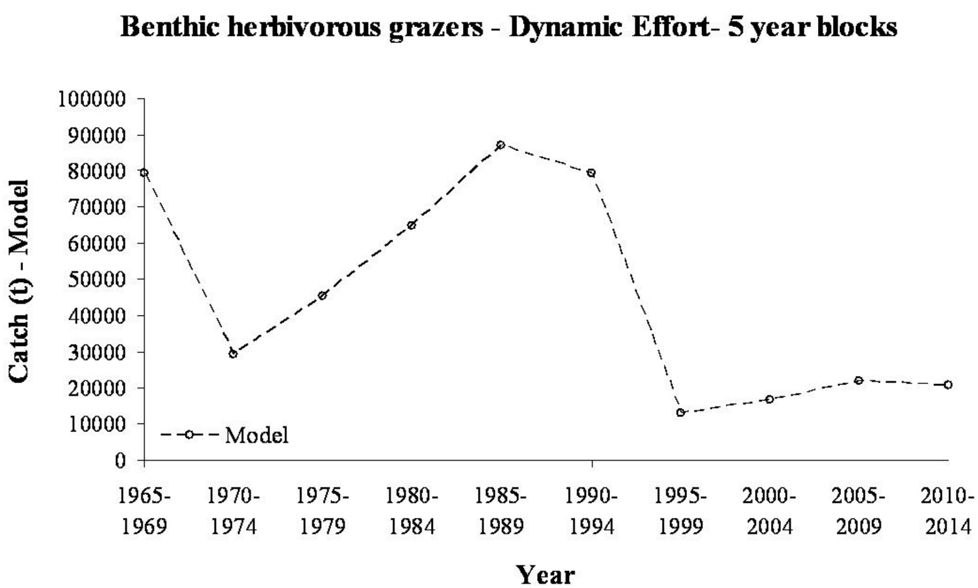


b.

Figure C19. Other benthic filter feeders catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.

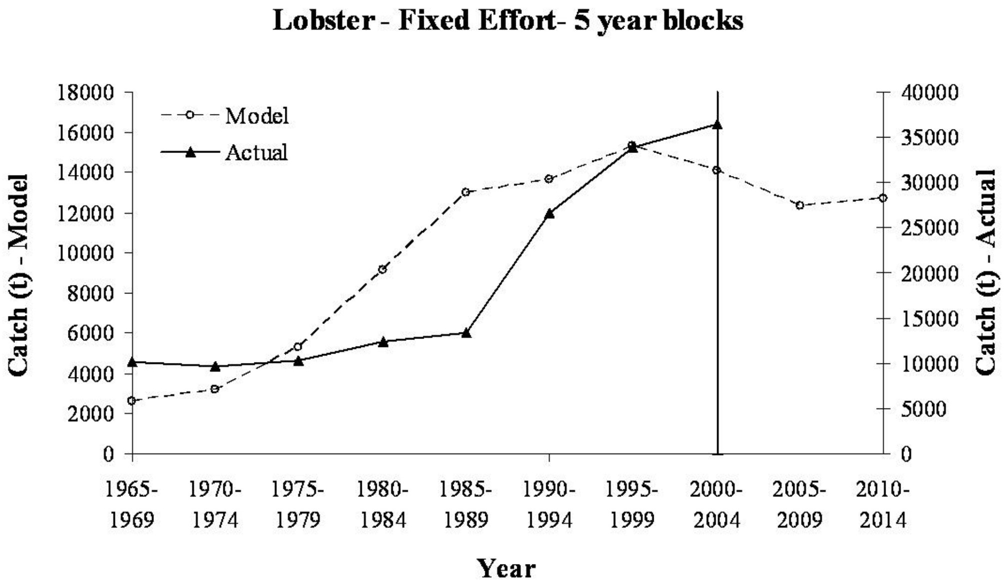


a.

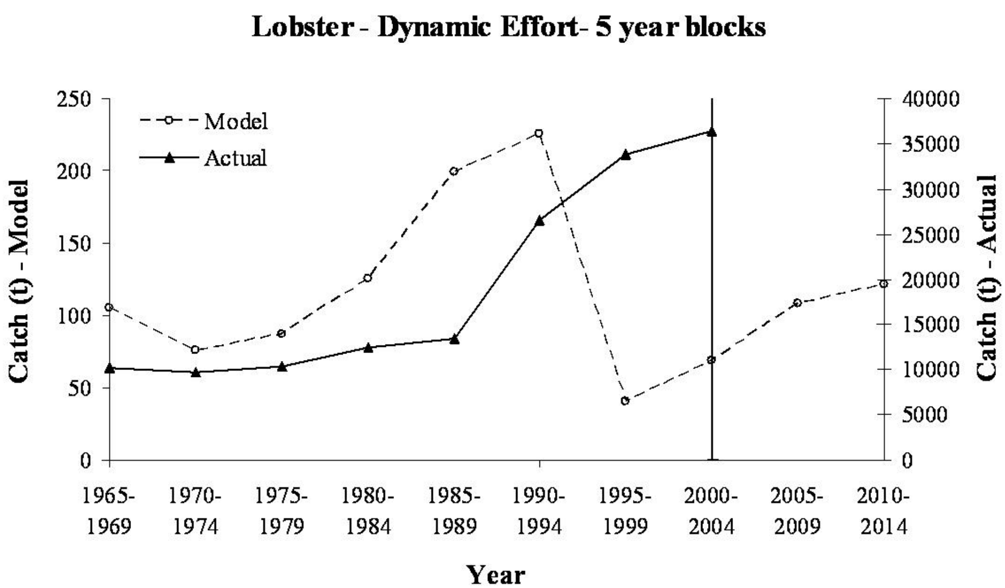


b.

Figure C20. Benthic herbivorous grazers catch trajectories for Atlantis NEUS (a. fixed effort run, b. dynamic effort run). No observed time series was available.

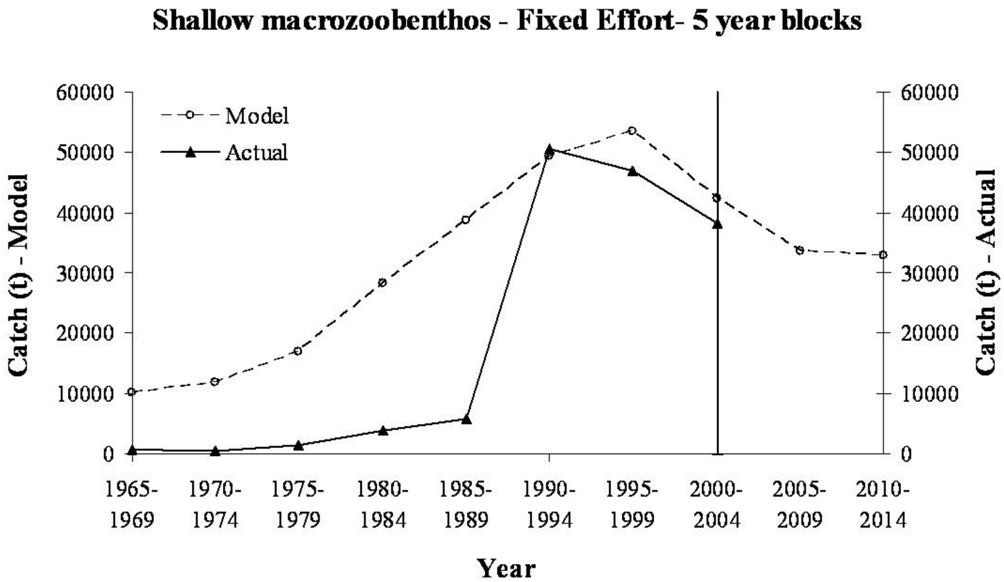


a.

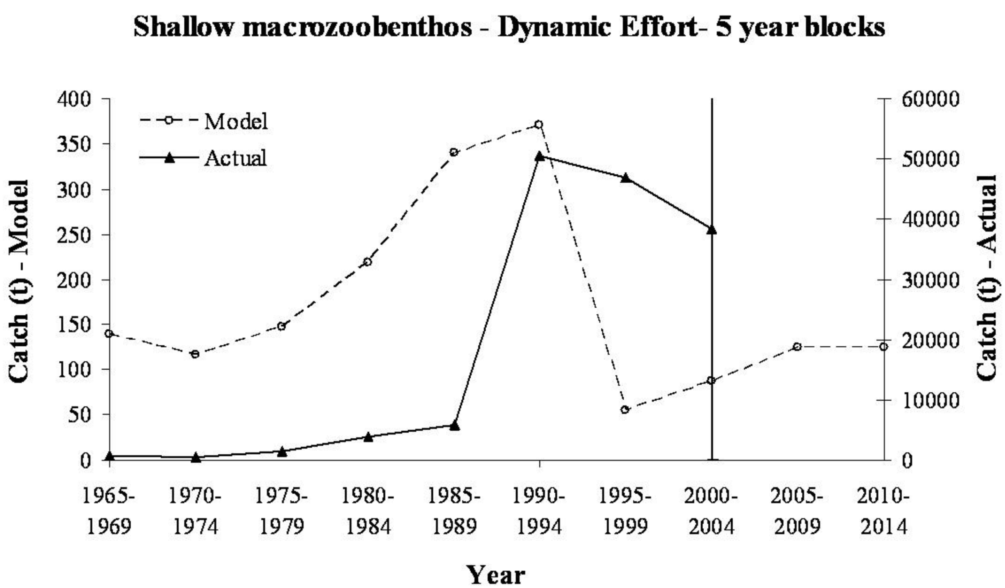


b.

Figure C21. Lobster (*Homarus americanus*) catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.

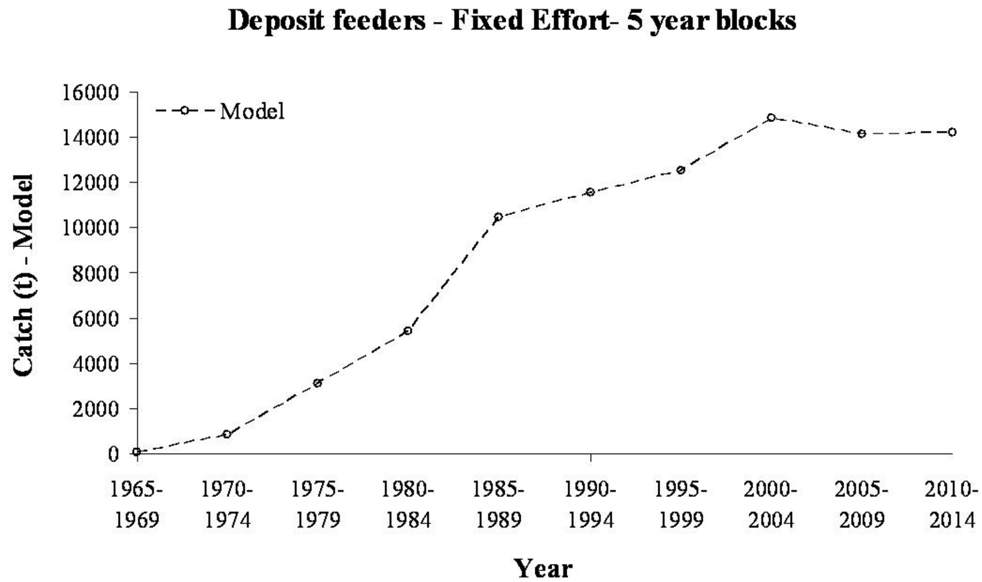


a.



b.

Figure C22. Shallow macrozoobenthos catch trajectories for both Atlantis NEUS (a. fixed effort run, b. dynamic effort run) and the actual observed time series.



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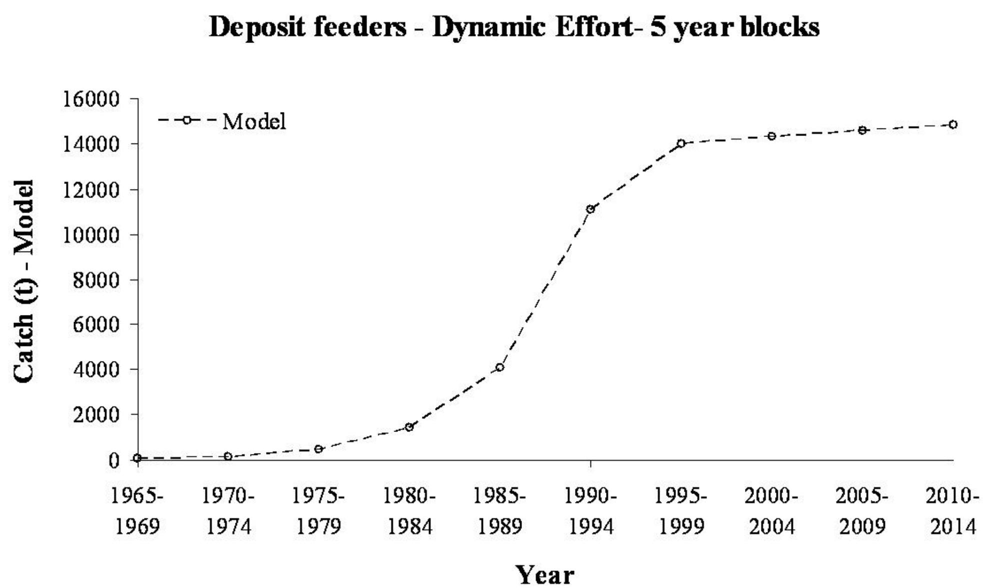
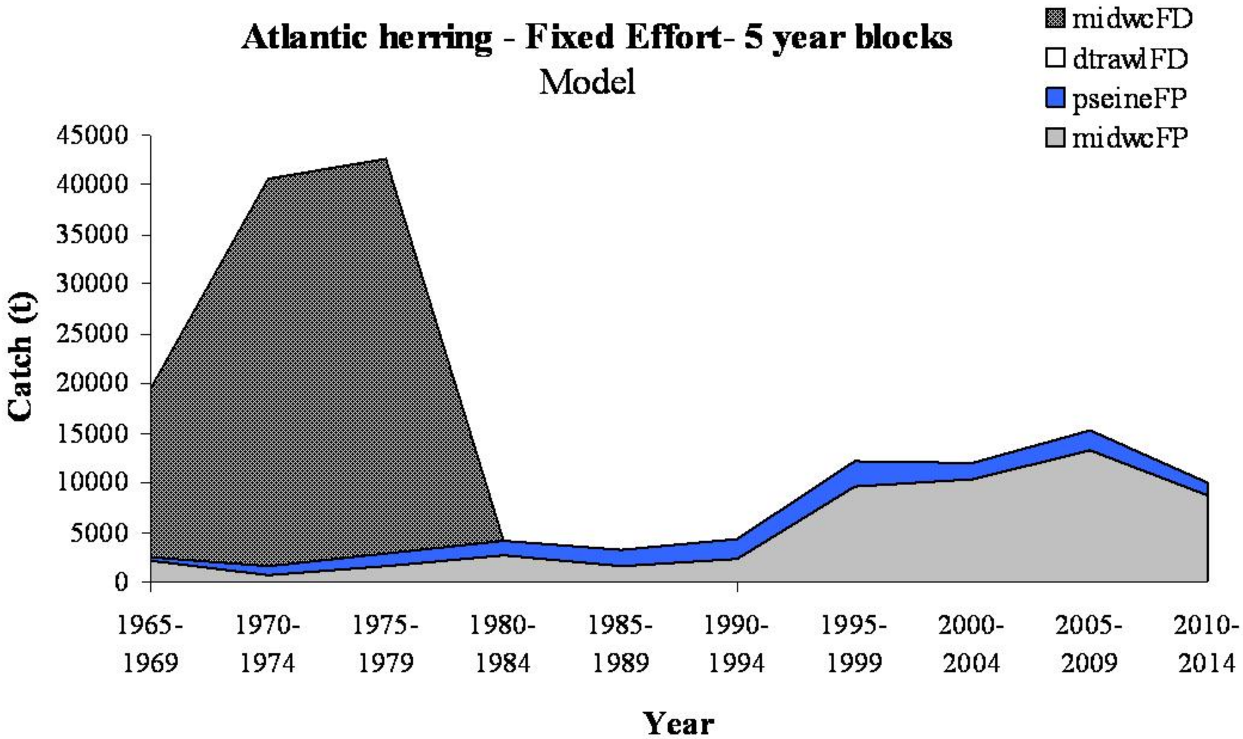


b.

Figure C23. Deposit feeders catch trajectories for Atlantis NEUS (a. fixed effort run, b. dynamic effort run). No observed time series was available.

APPENDIX D: Atlantis NEUS – CATCH PER FISHERY TRAJECTORY RESULTS



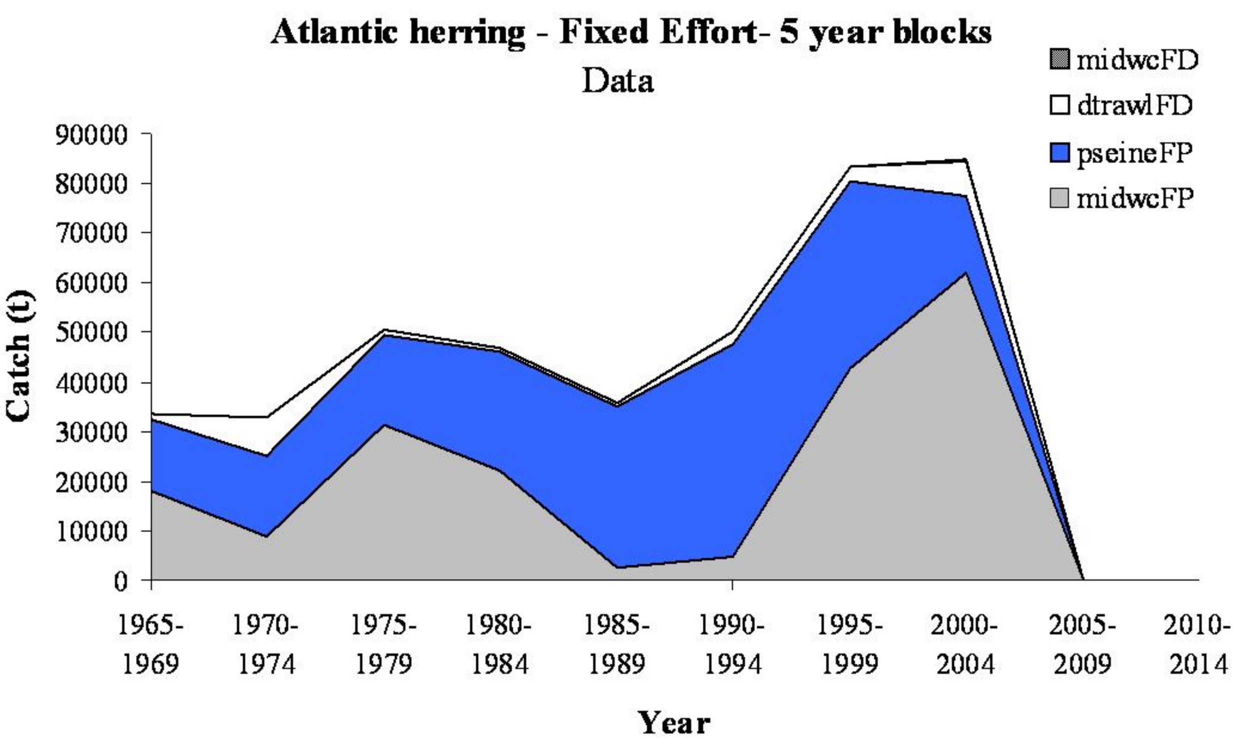
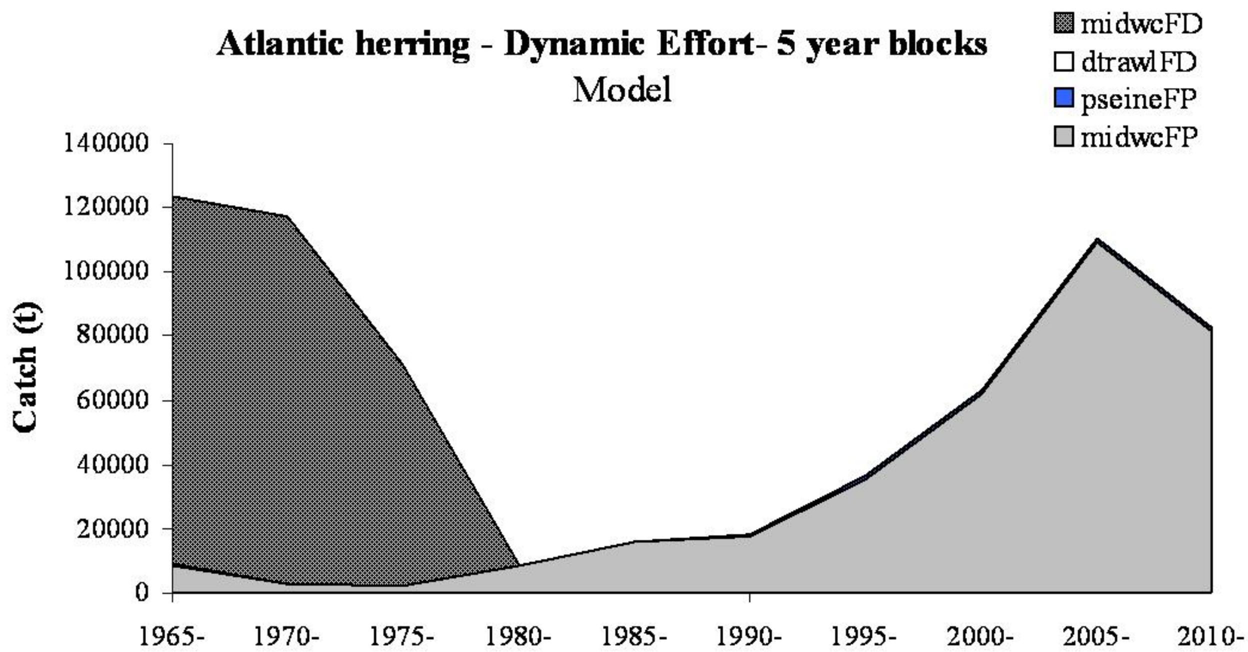


Figure D1. Atlantic herring (*Clupea harengus*) catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



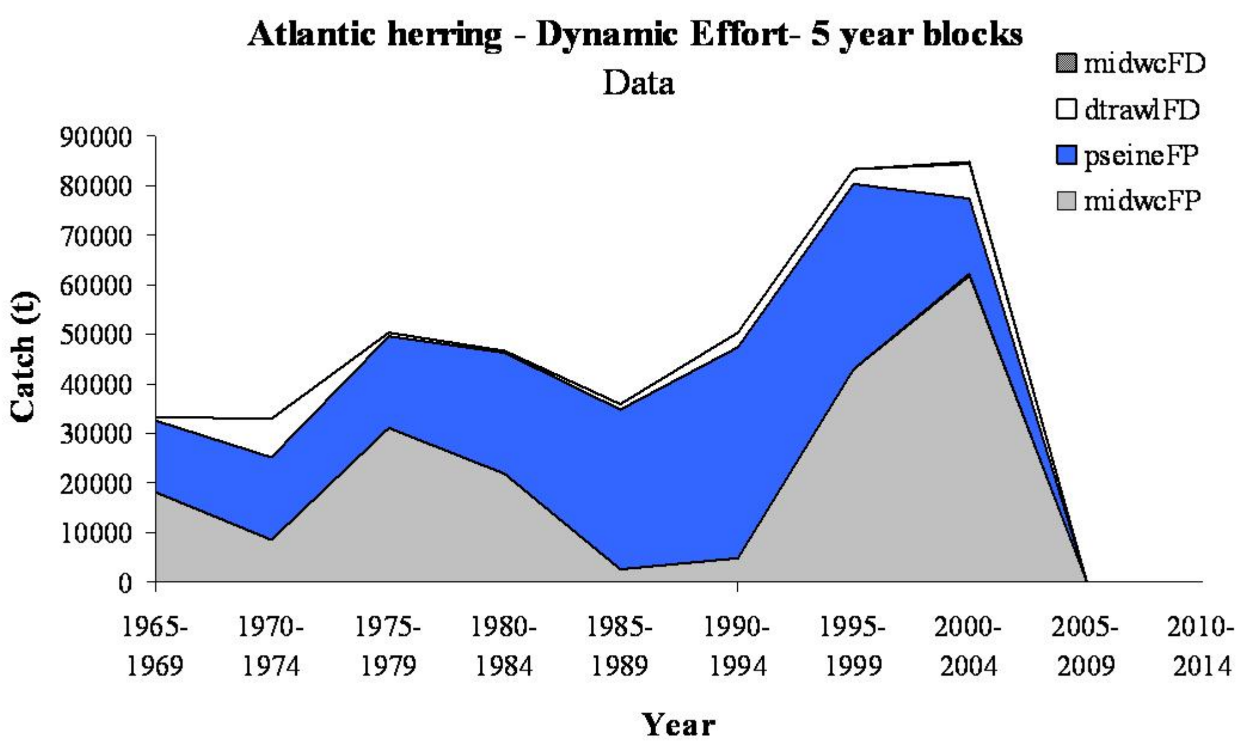
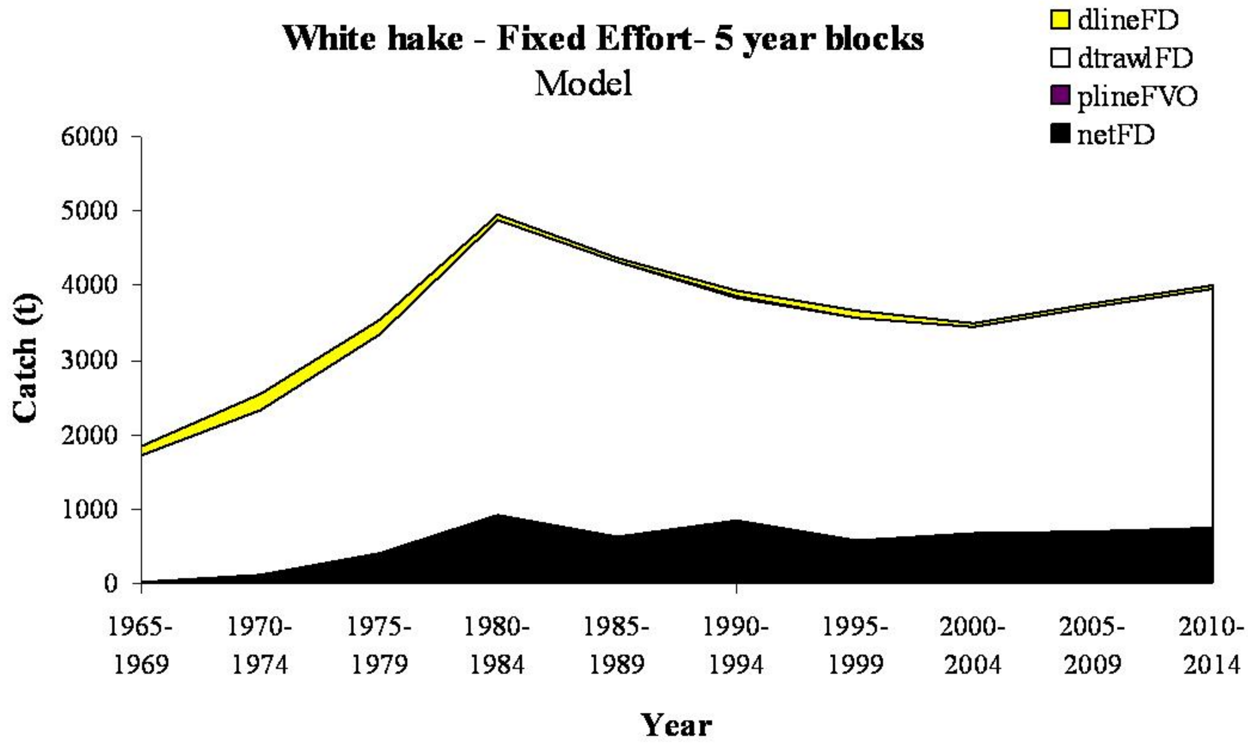


Figure D2. Atlantic herring (*Clupea harengus*) catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



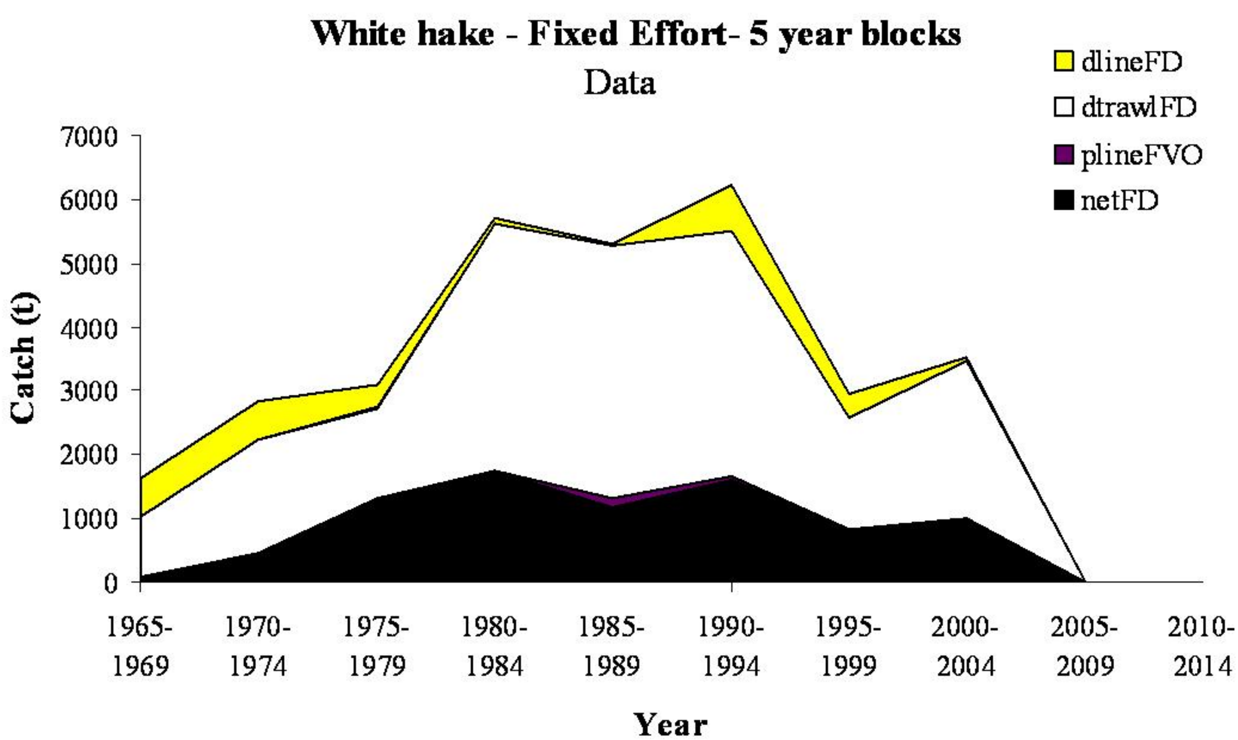
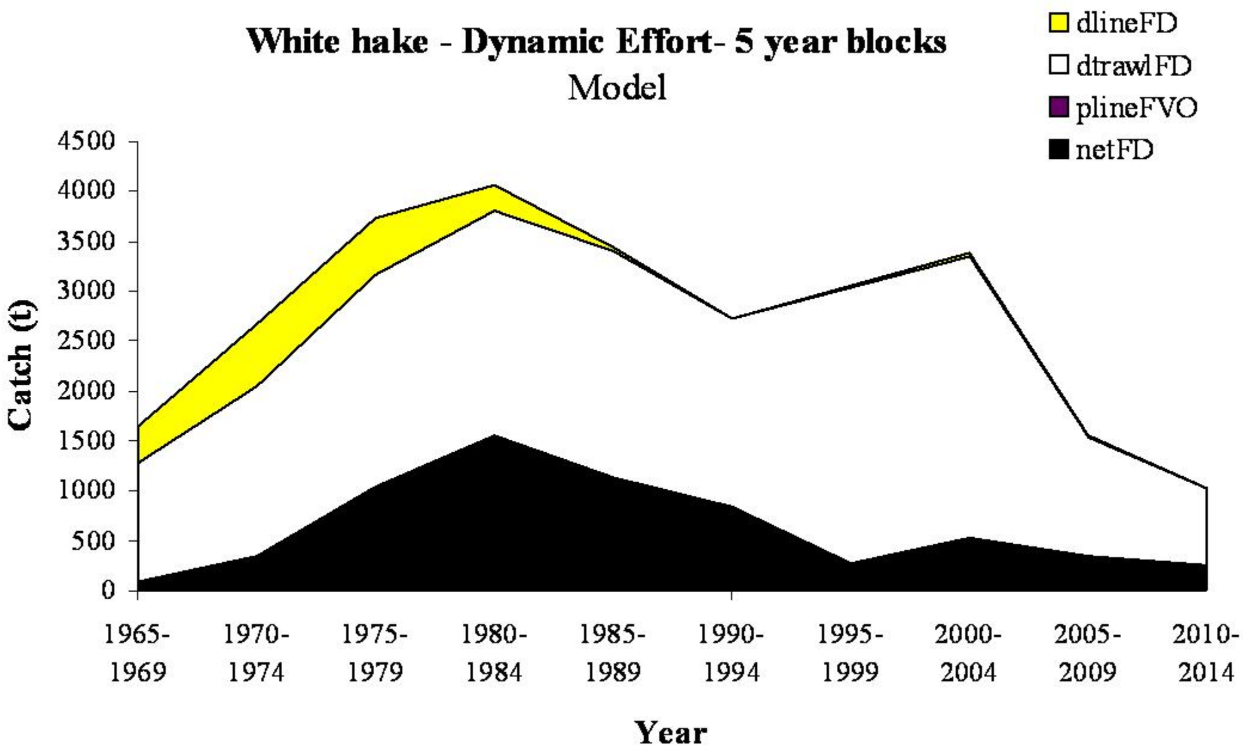


Figure D3. White hake (*Urophycis tenuis*) catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



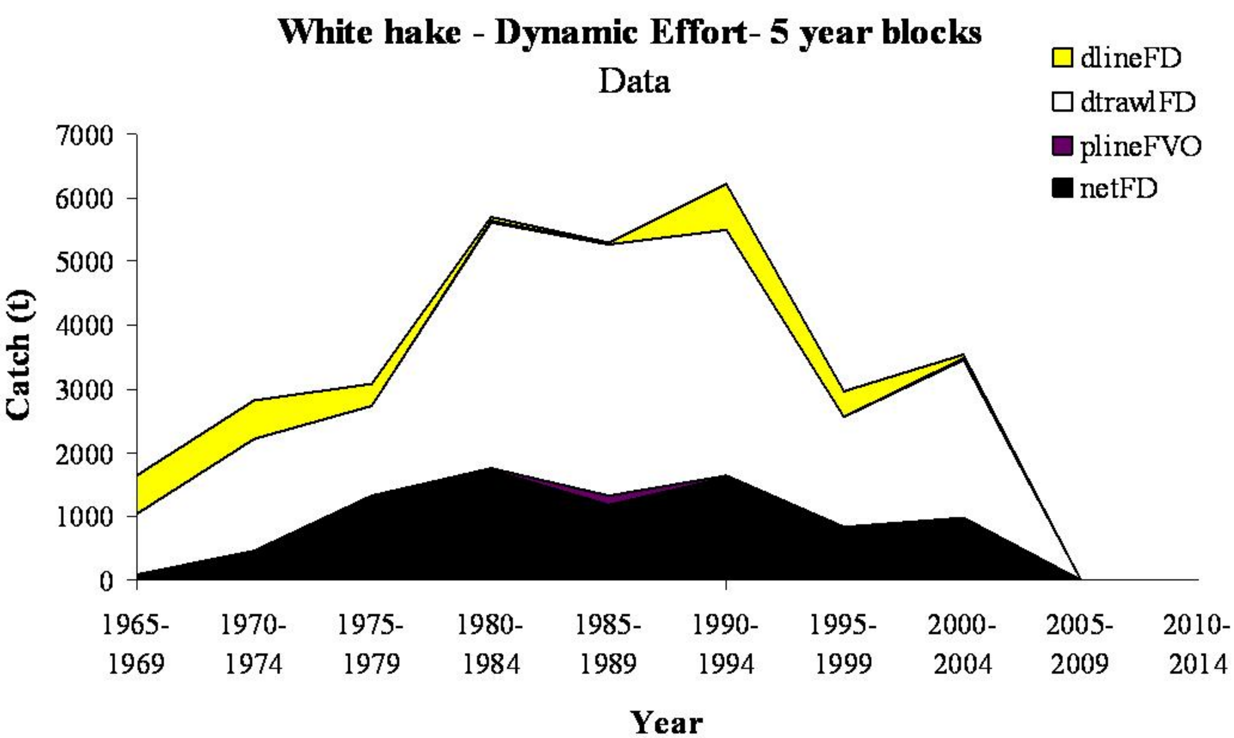
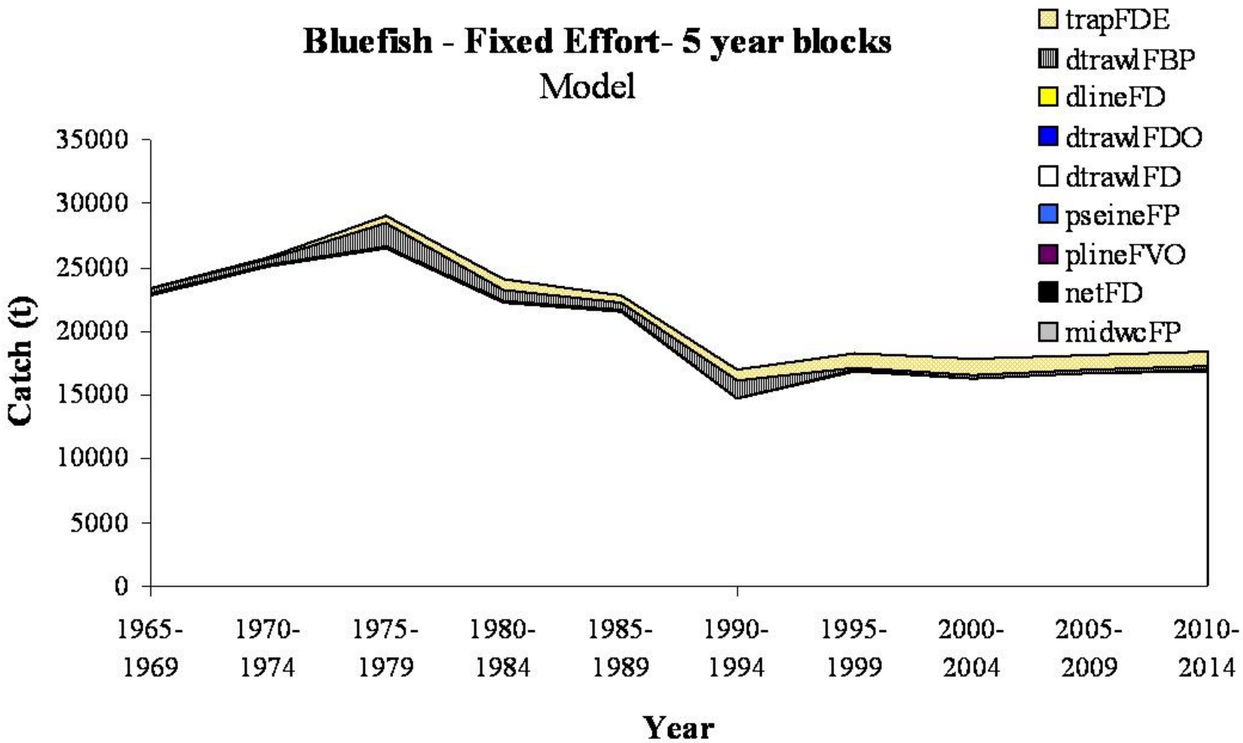


Figure D4. White hake (*Urophycis tenuis*) catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



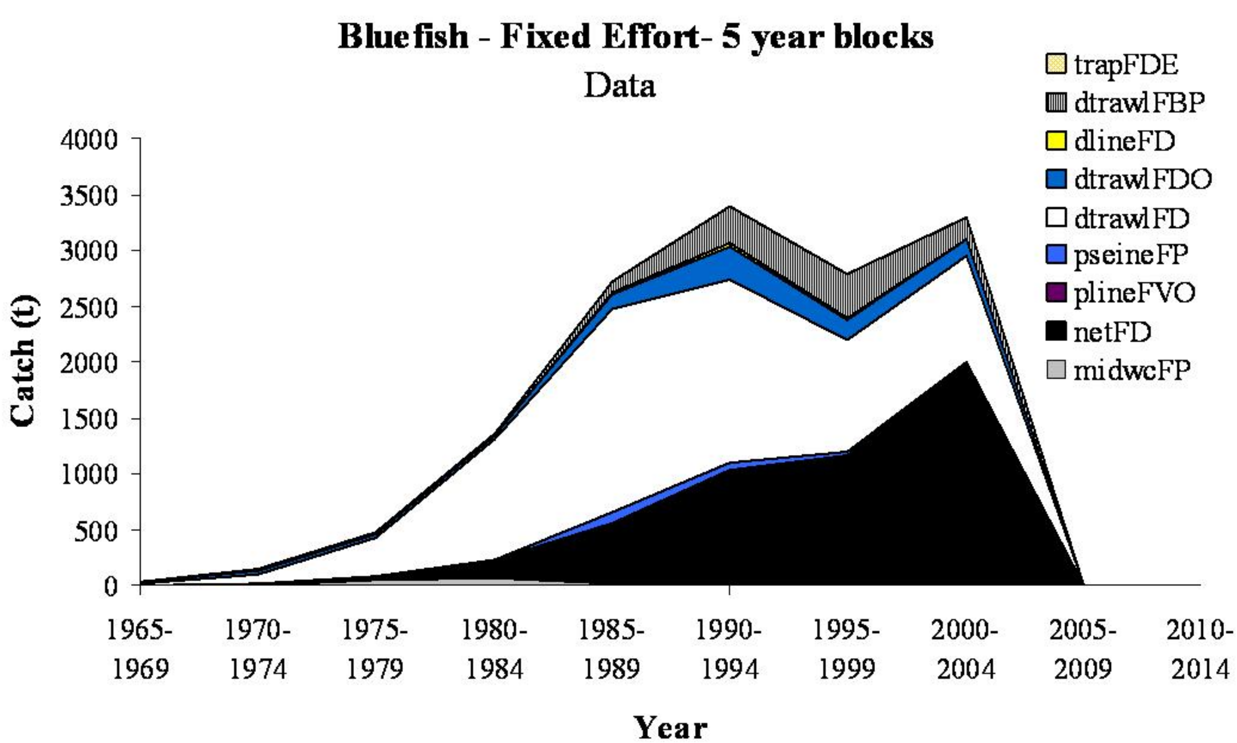
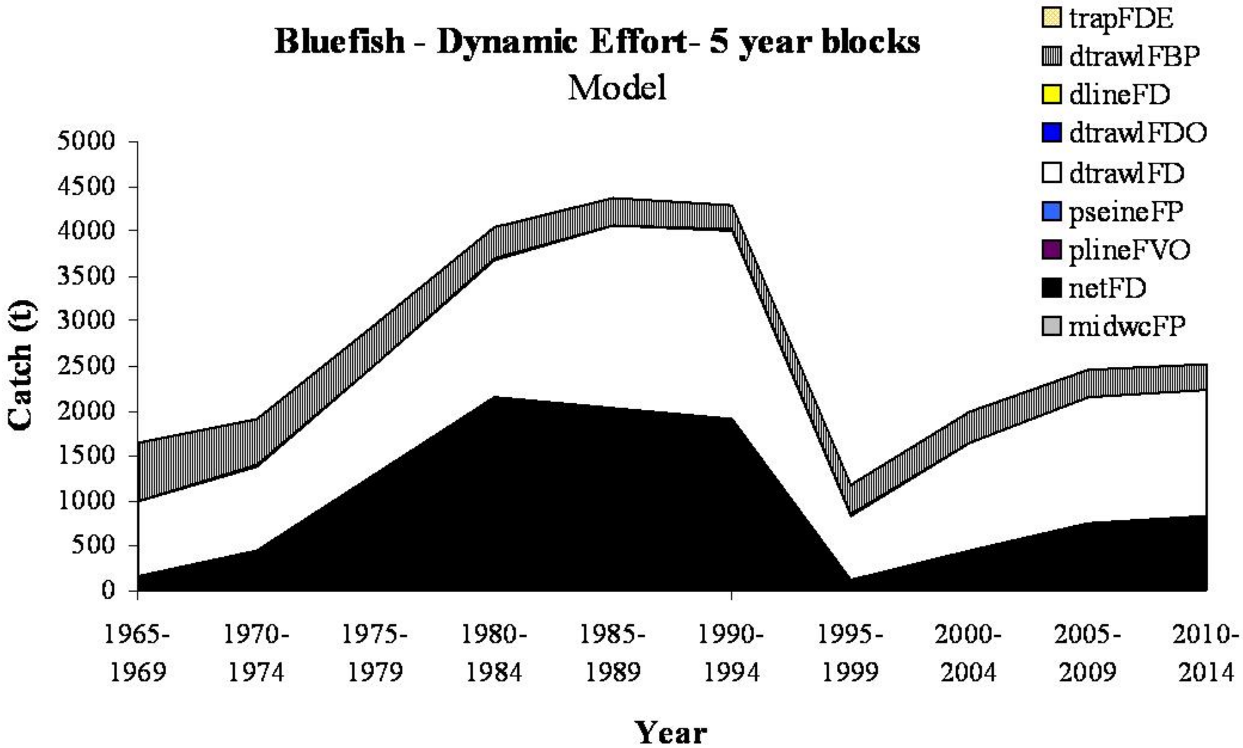


Figure D5. Bluefish (*Pomatomus saltatrix*) catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



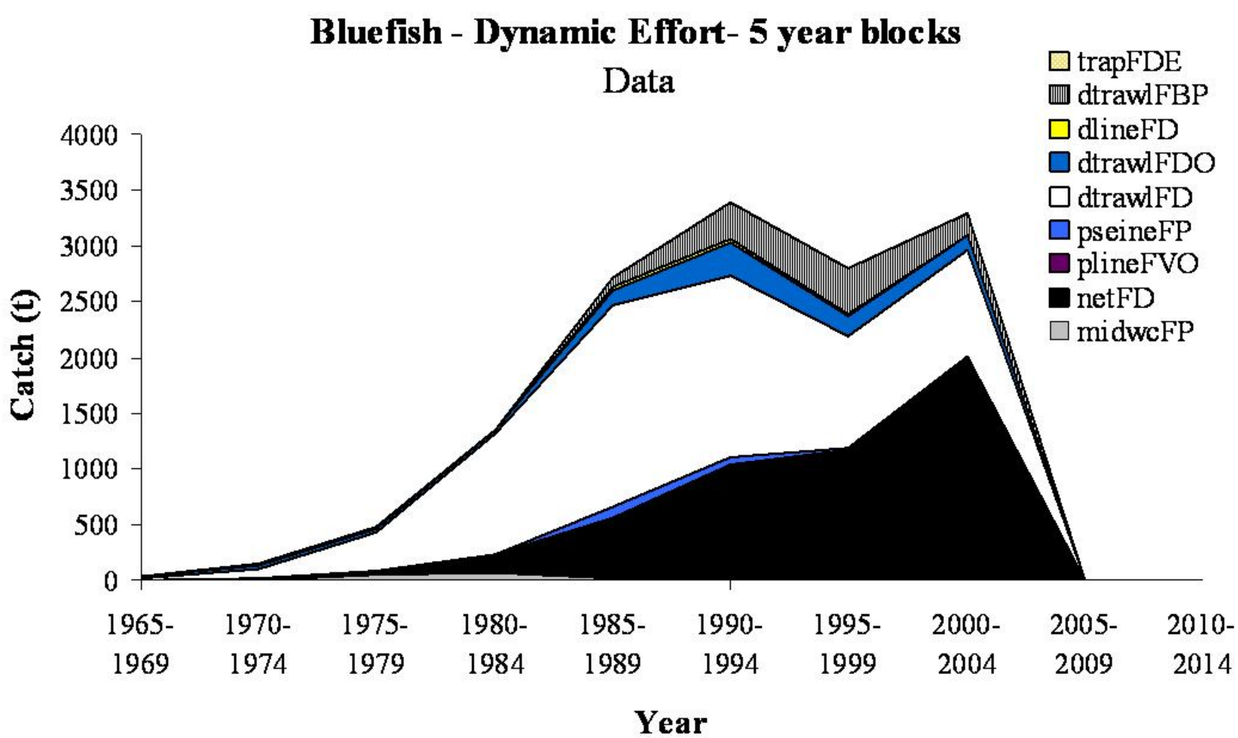
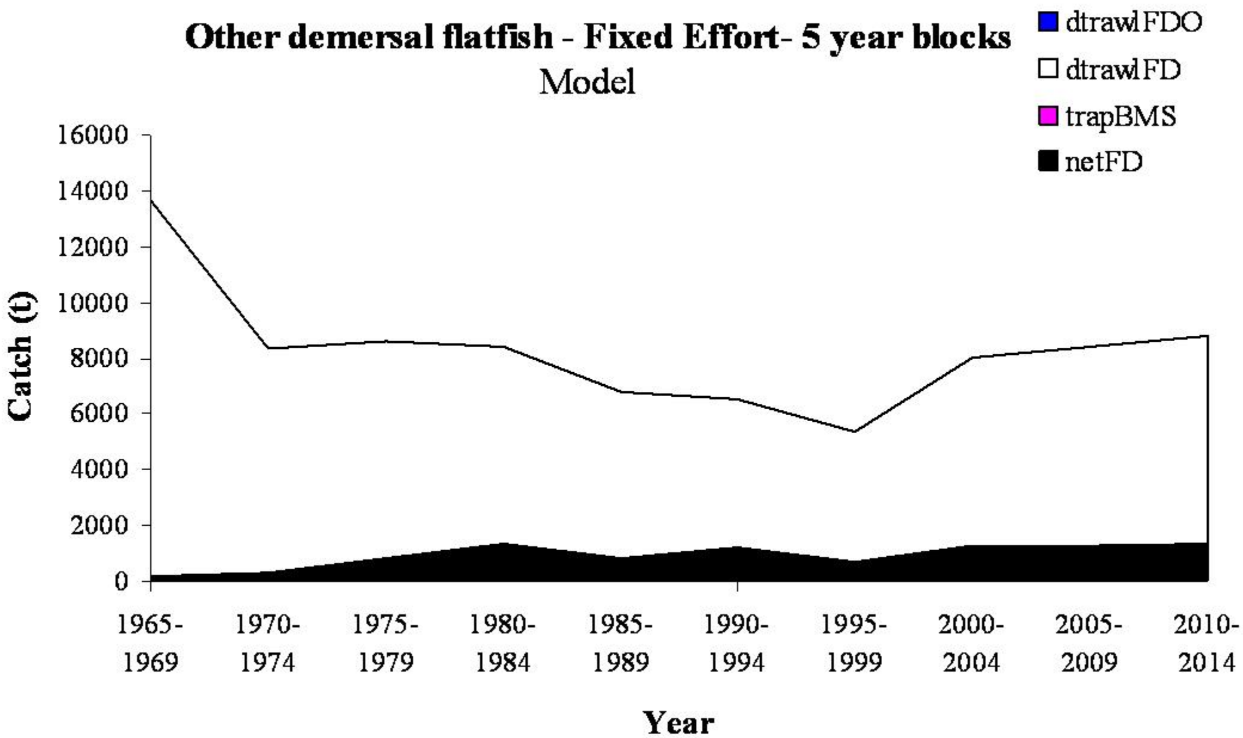


Figure D6. Bluefish (*Pomatomus saltatrix*) catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



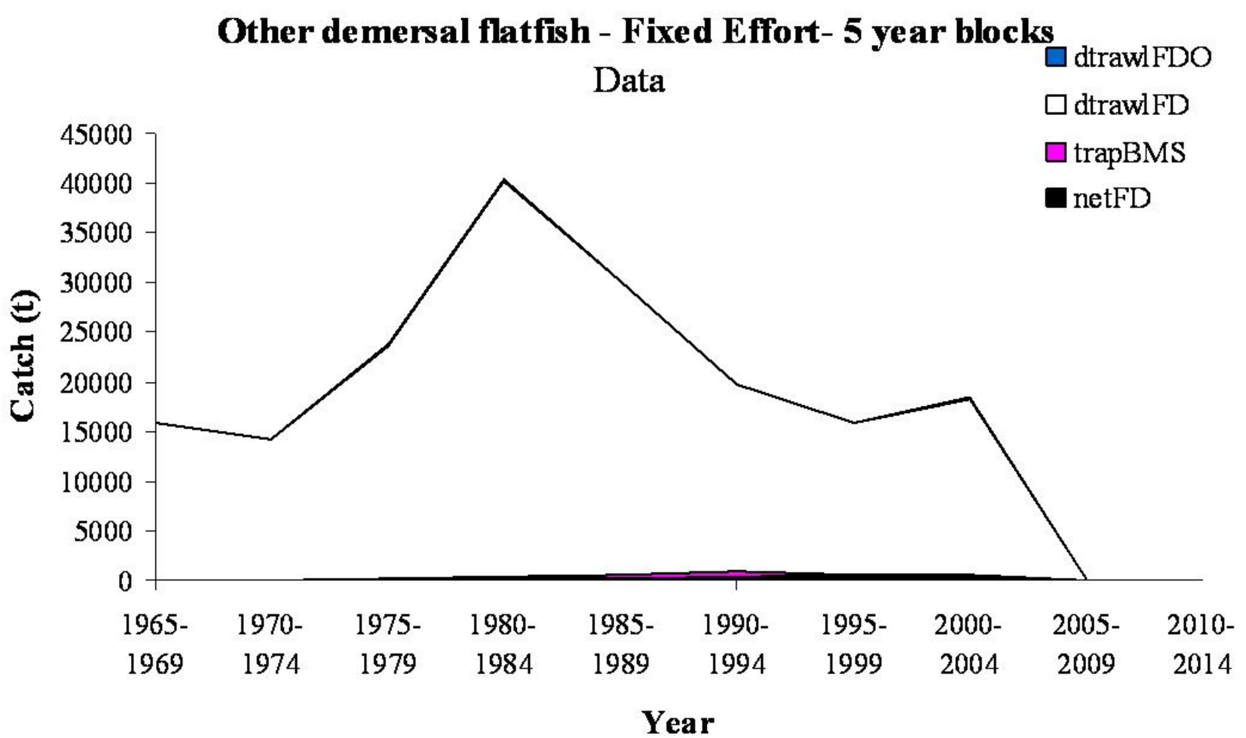
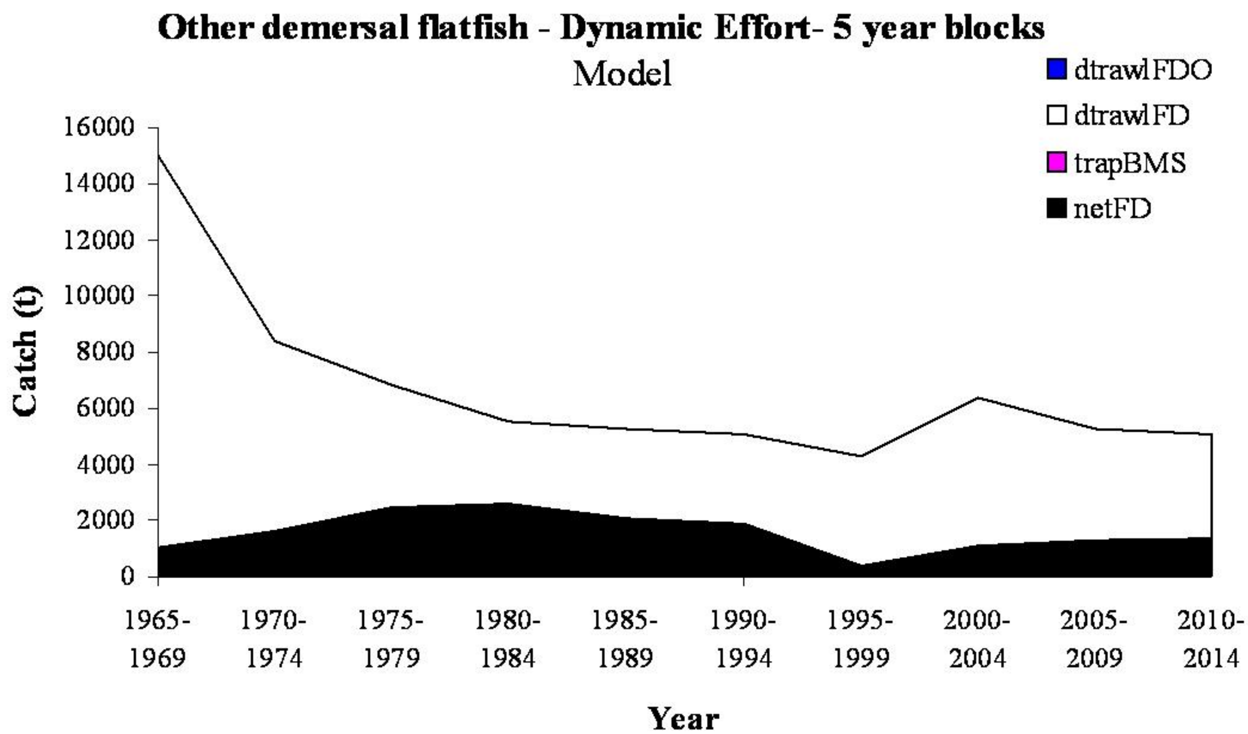


Figure D7. Other demersal flatfish catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



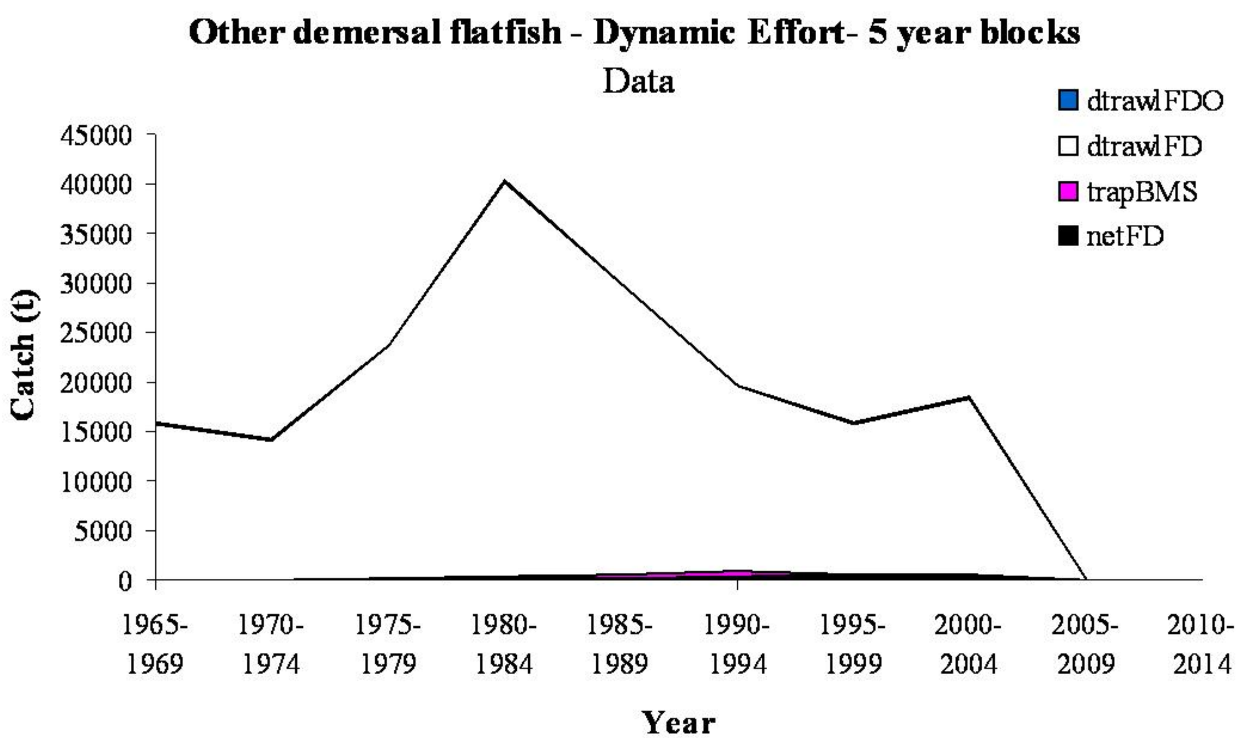


Figure D8. Other demersal flatfish catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

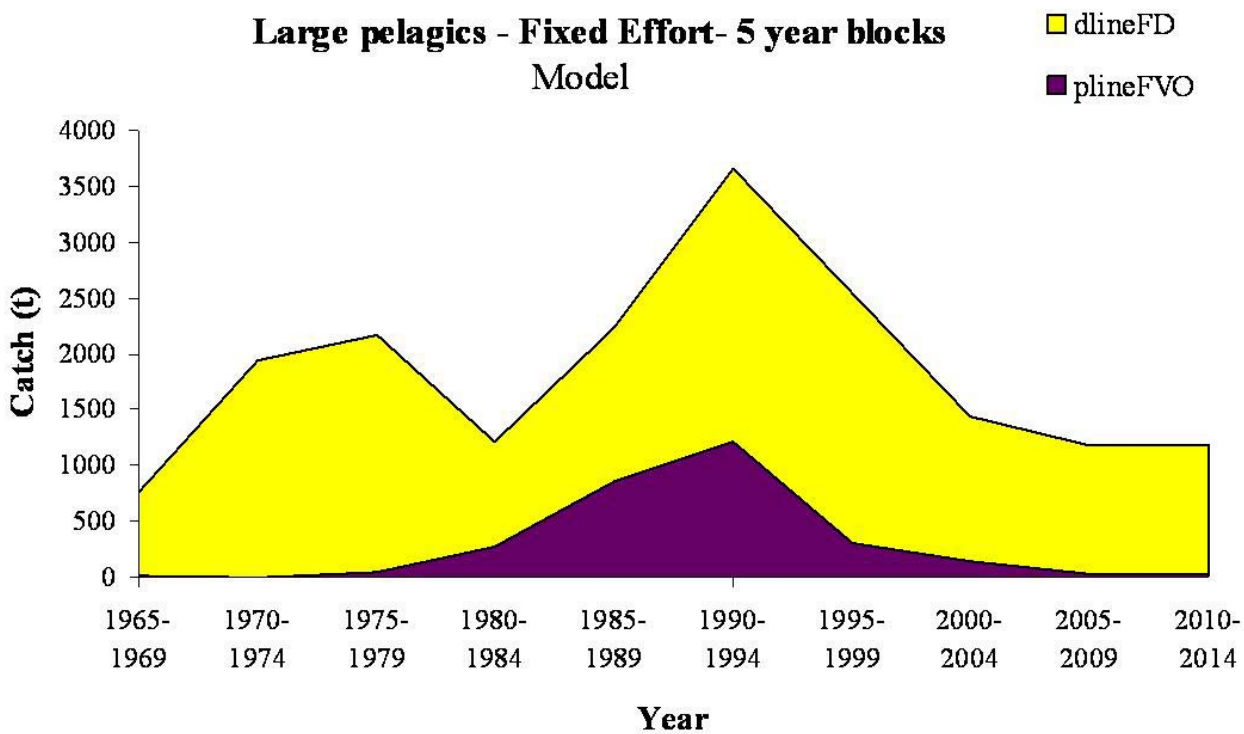


Figure D9. Large pelagics catch per fishery trajectory for Atlantis NEUS (fixed effort run). No observed time series was available.

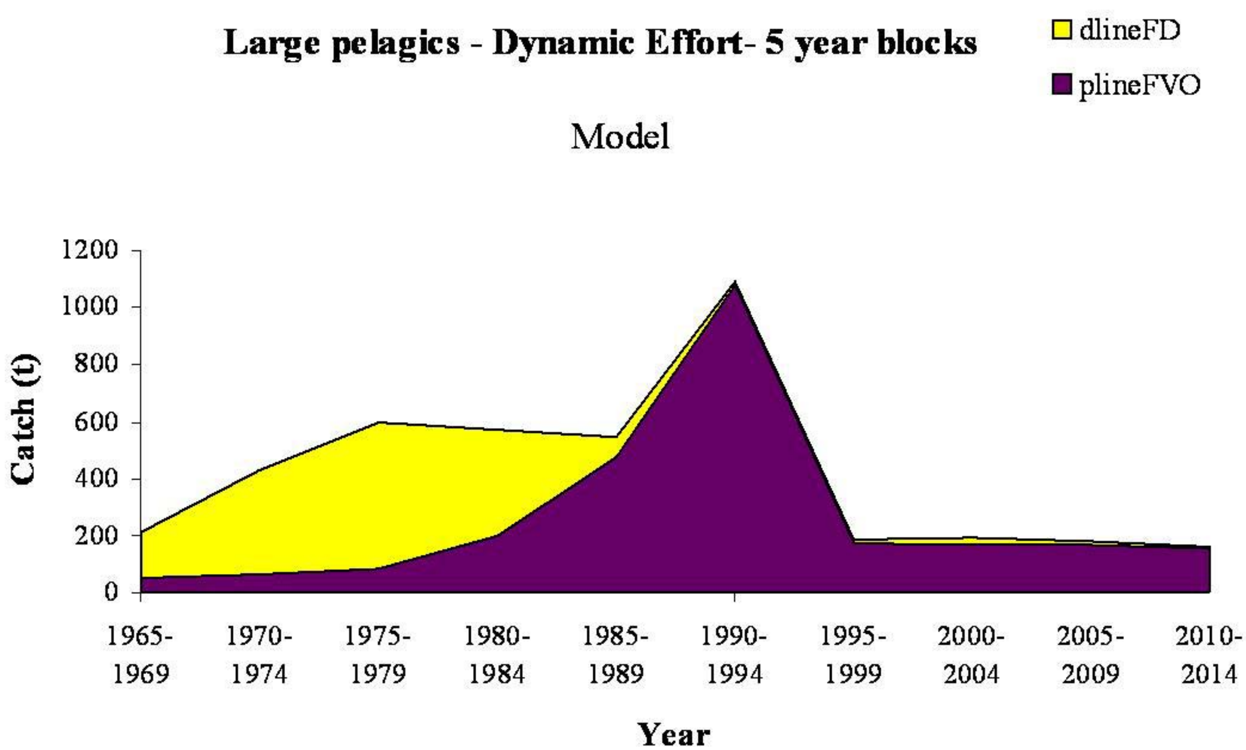


Figure D10. Large pelagics catch per fishery trajectory for Atlantis NEUS (dynamic effort run). No observed time series was available.

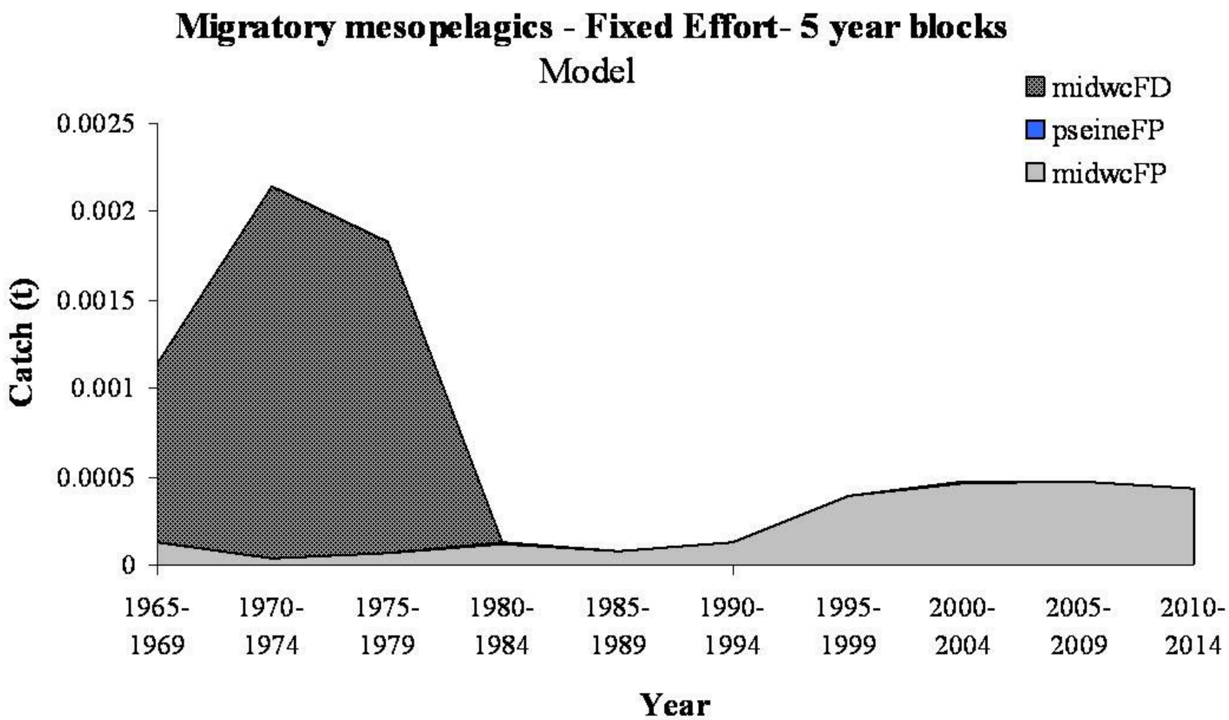


Figure D11. Migratory mesopelagics catch per fishery trajectory for Atlantis NEUS (fixed effort run). No observed time series was available.

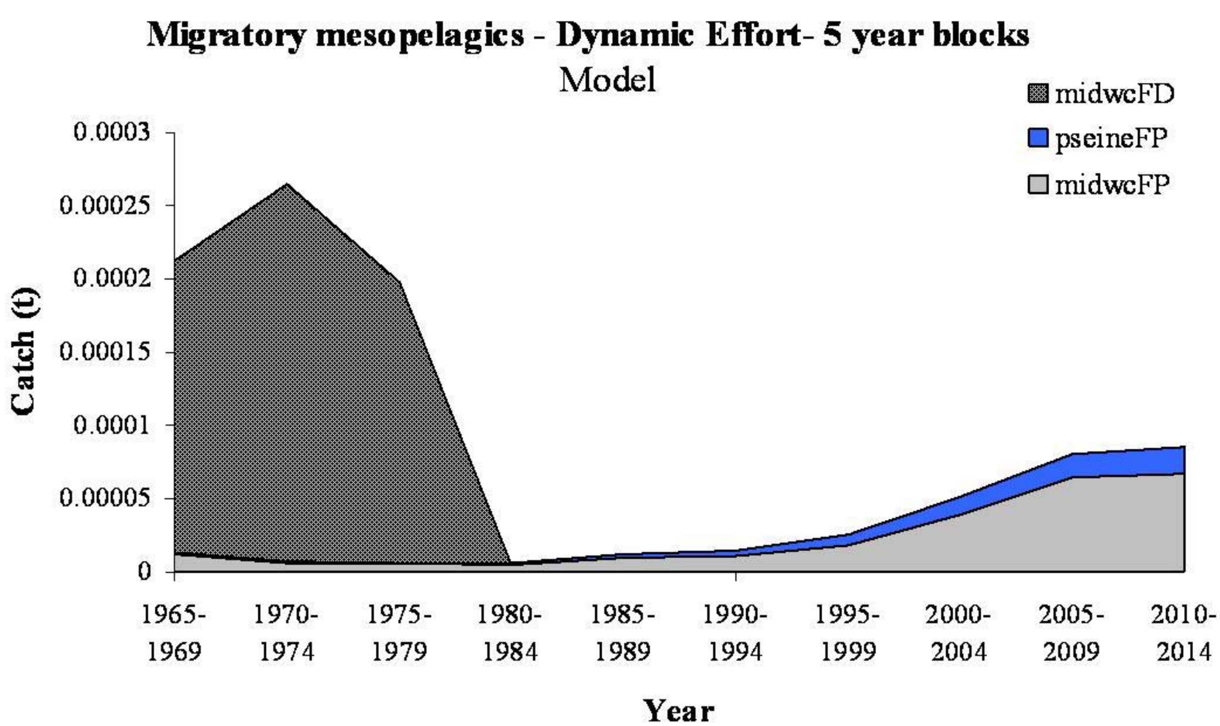
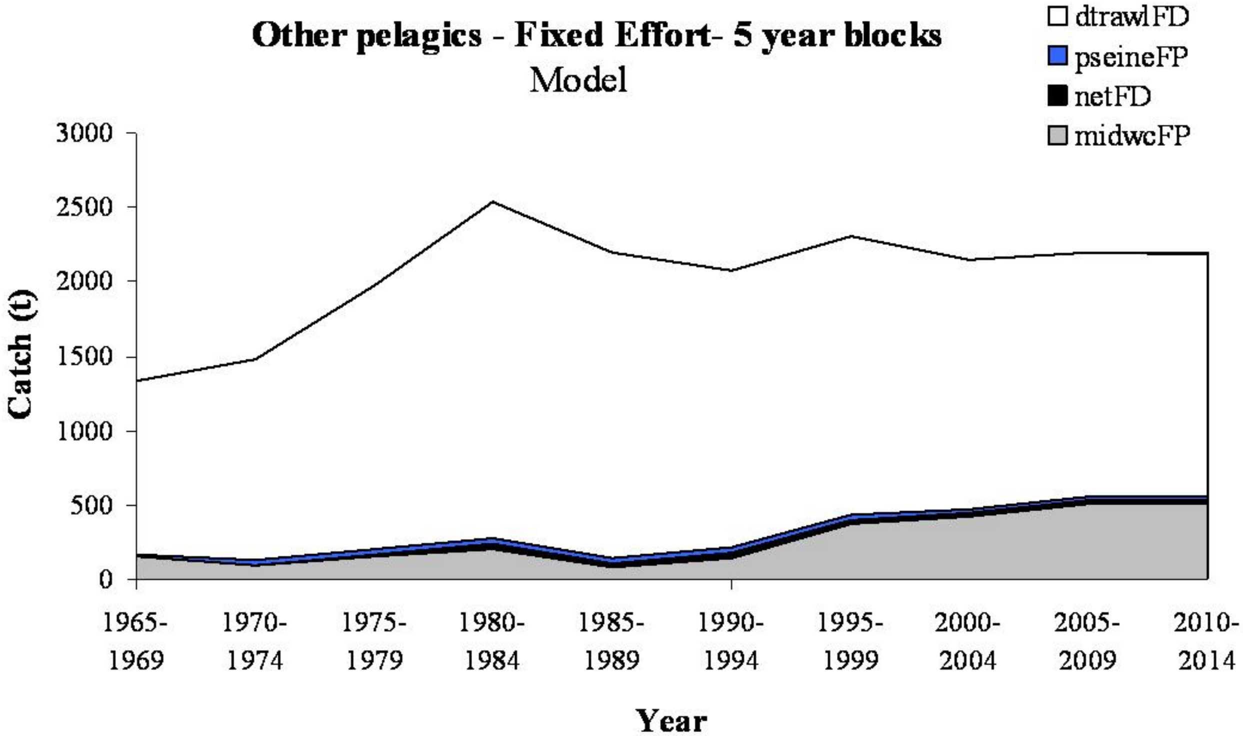


Figure D12. Migratory mesopelagics catch per fishery trajectory for Atlantis NEUS (dynamic effort run). No observed time series was available.



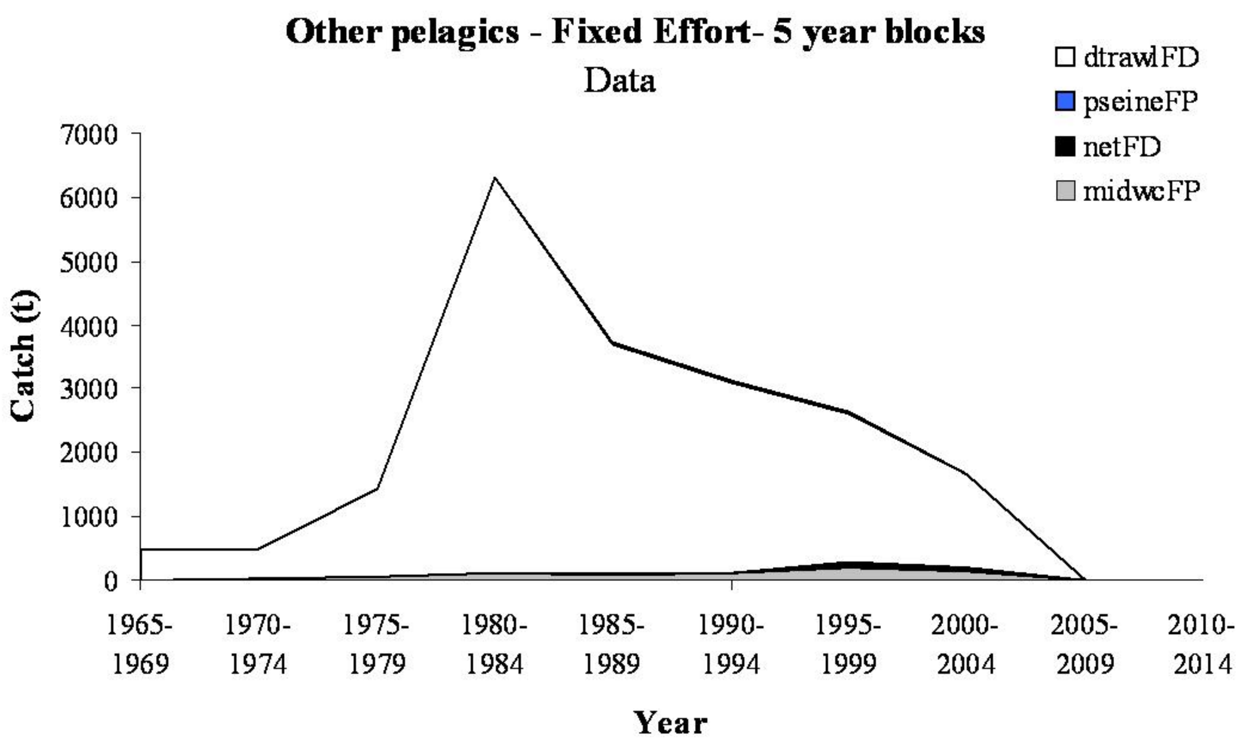
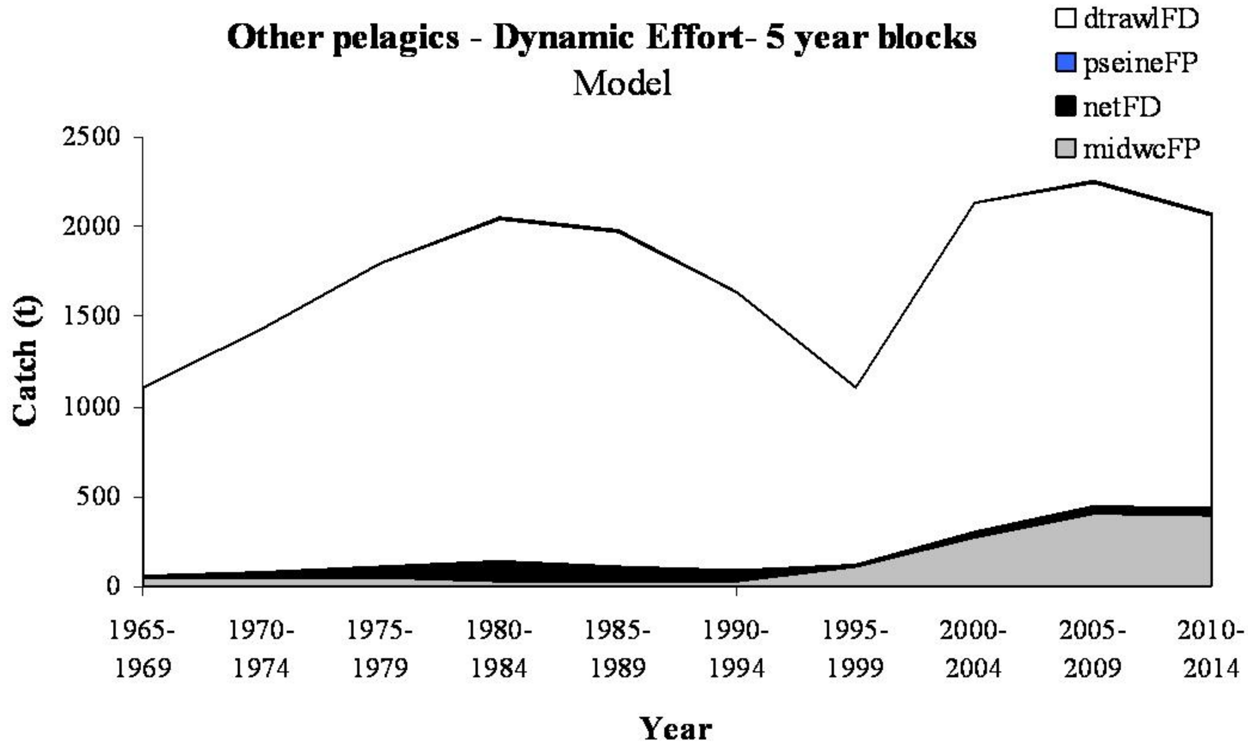


Figure D13. Other pelagics catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



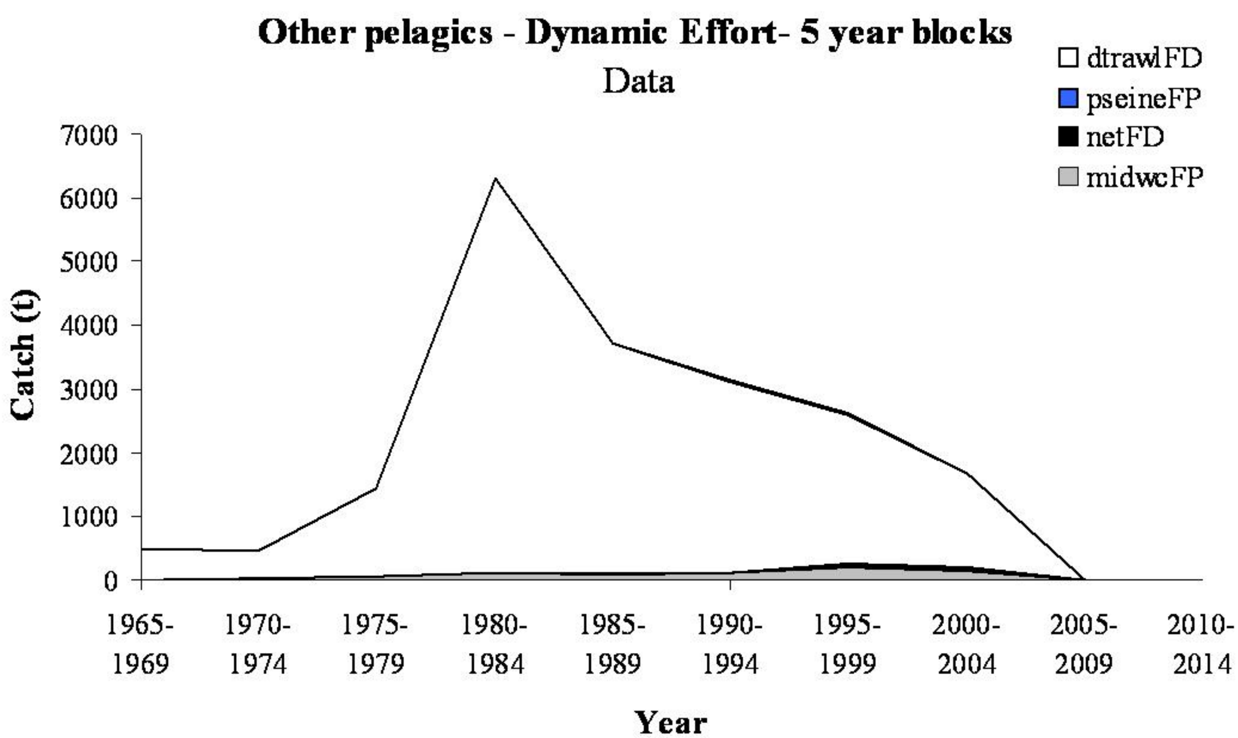
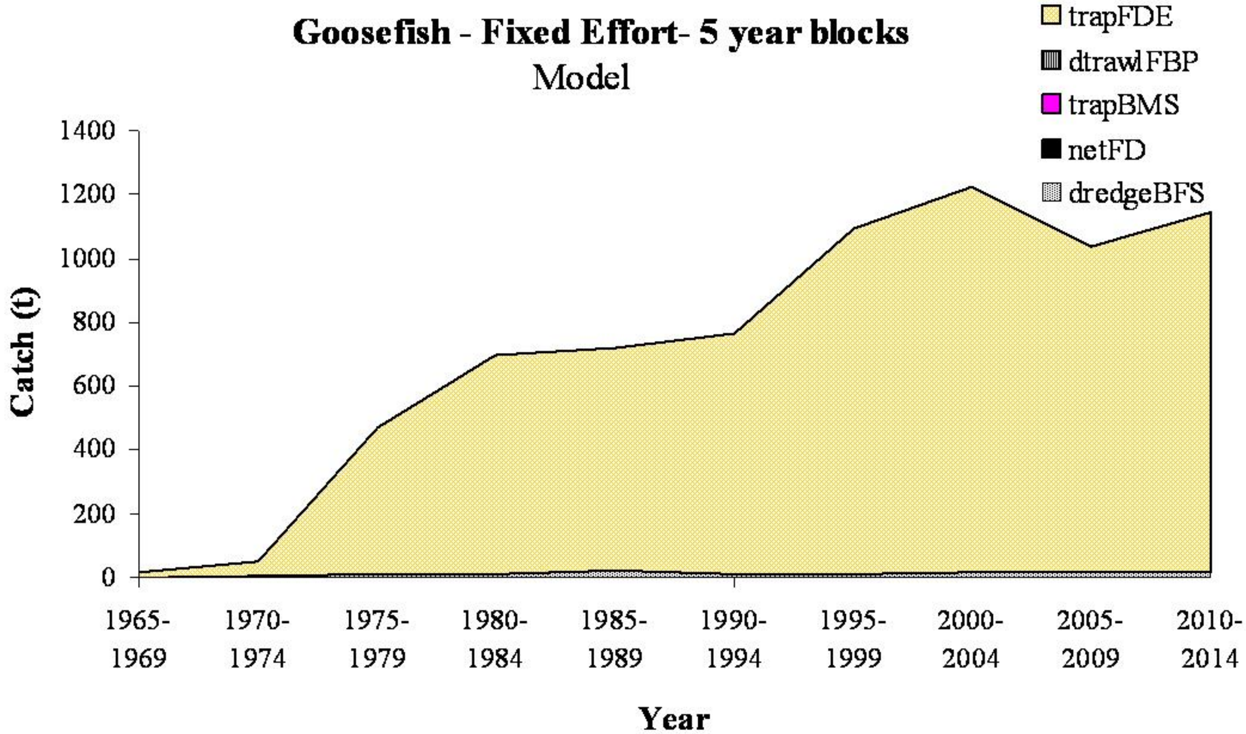


Figure D14. Other pelagics catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



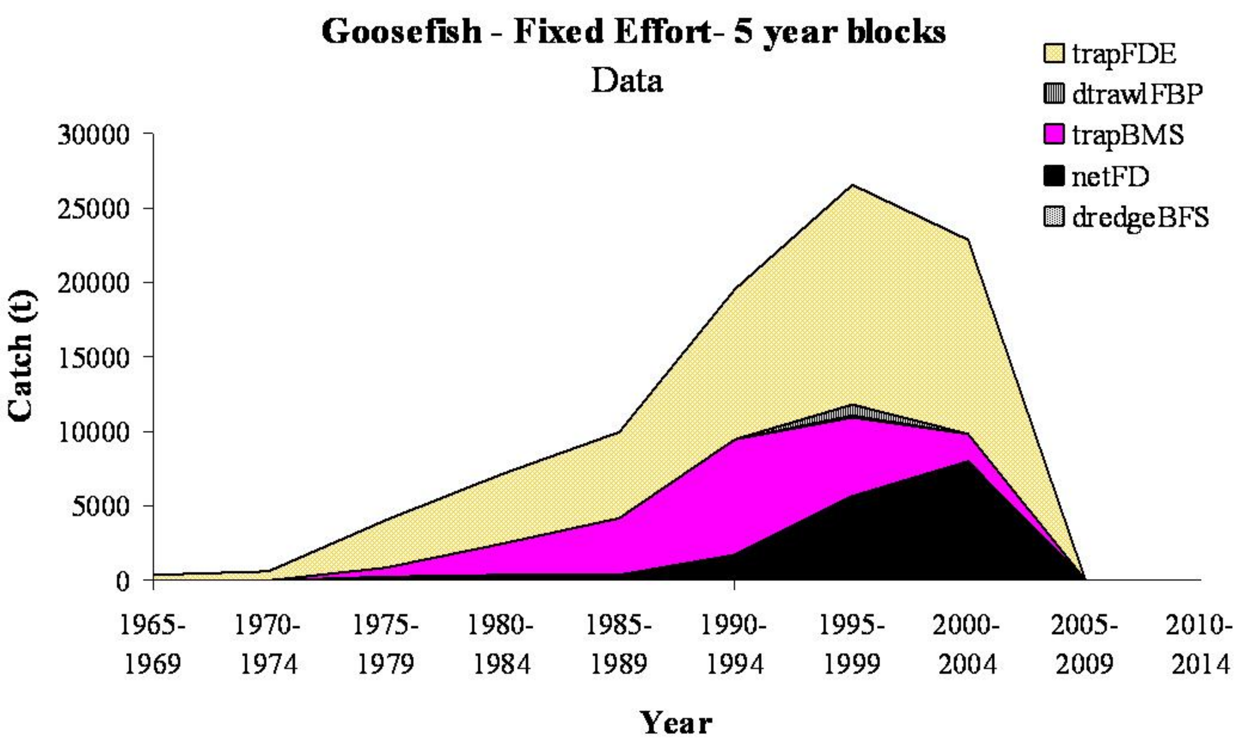
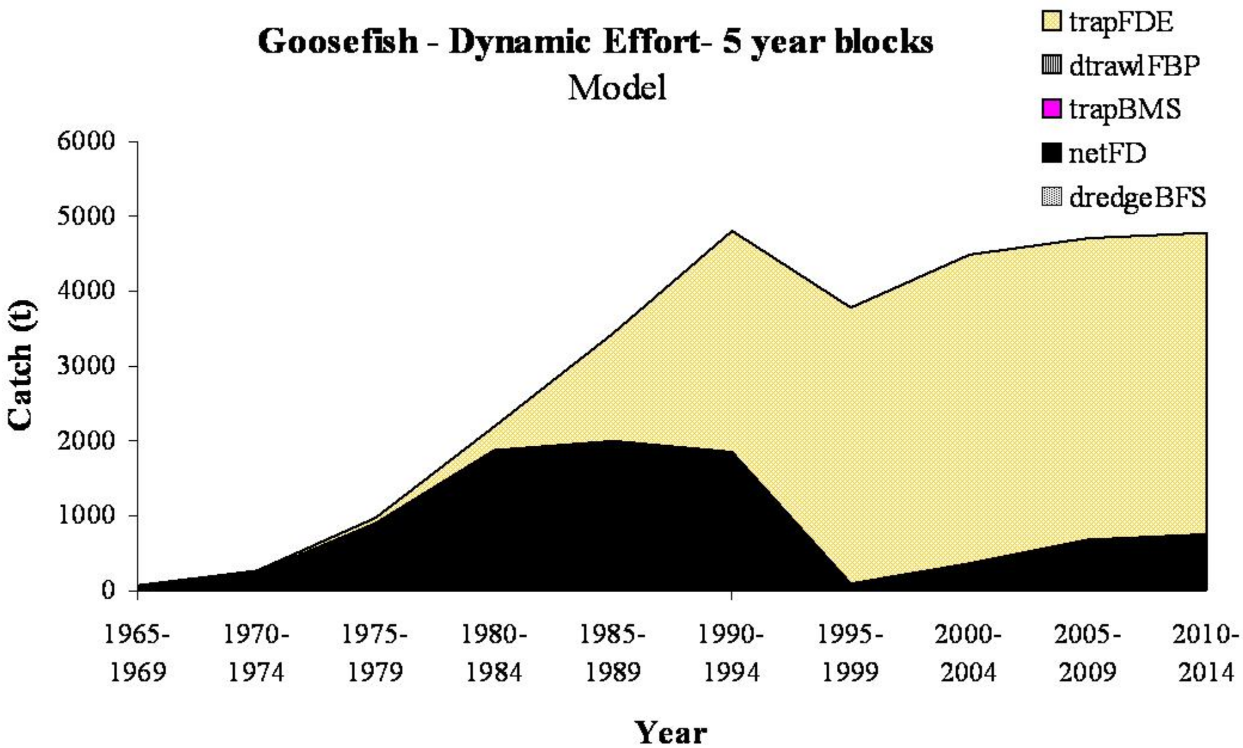


Figure D15. Goosefish (*Lophius americanus*) catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



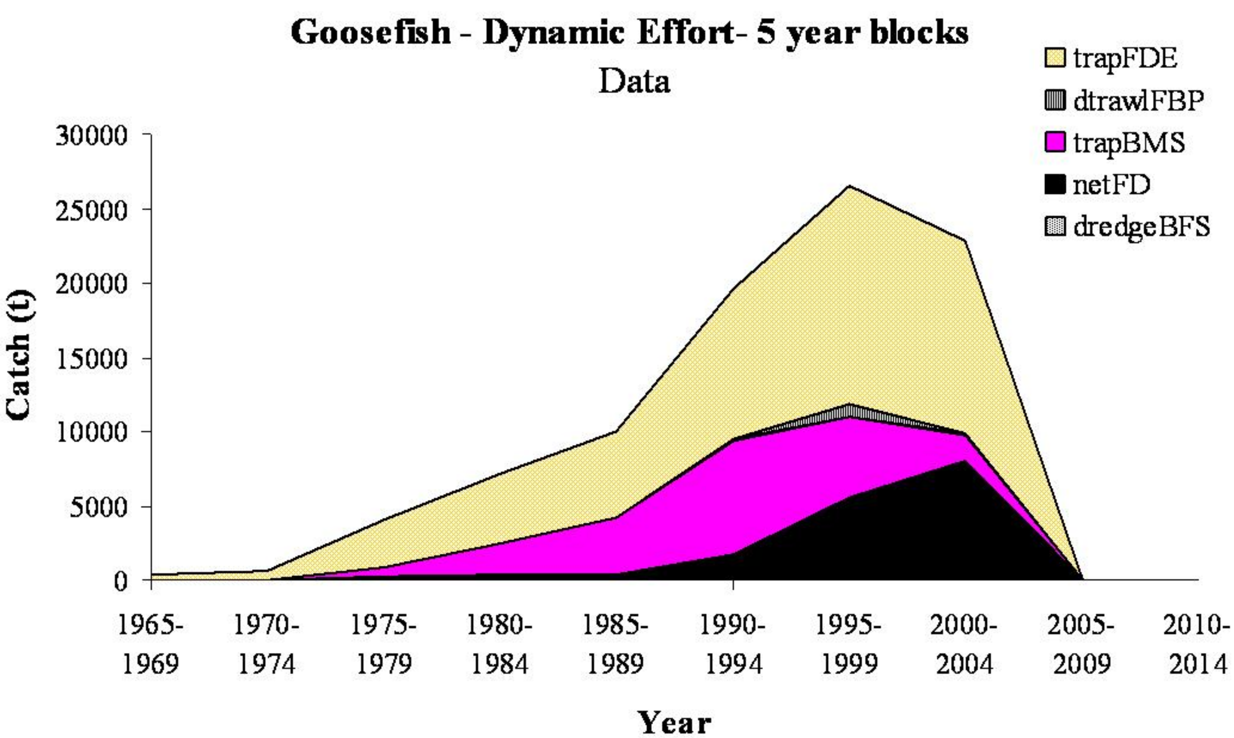
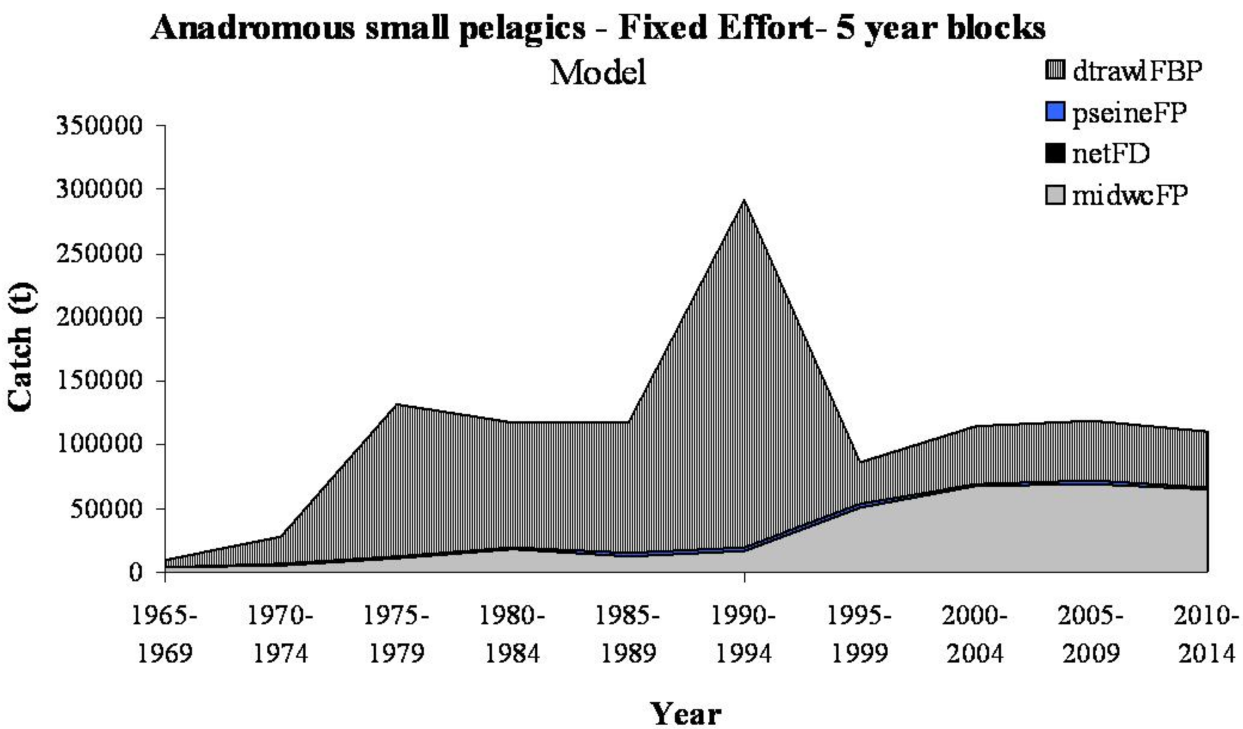


Figure D16. Goosefish (*Lophius americanus*) catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



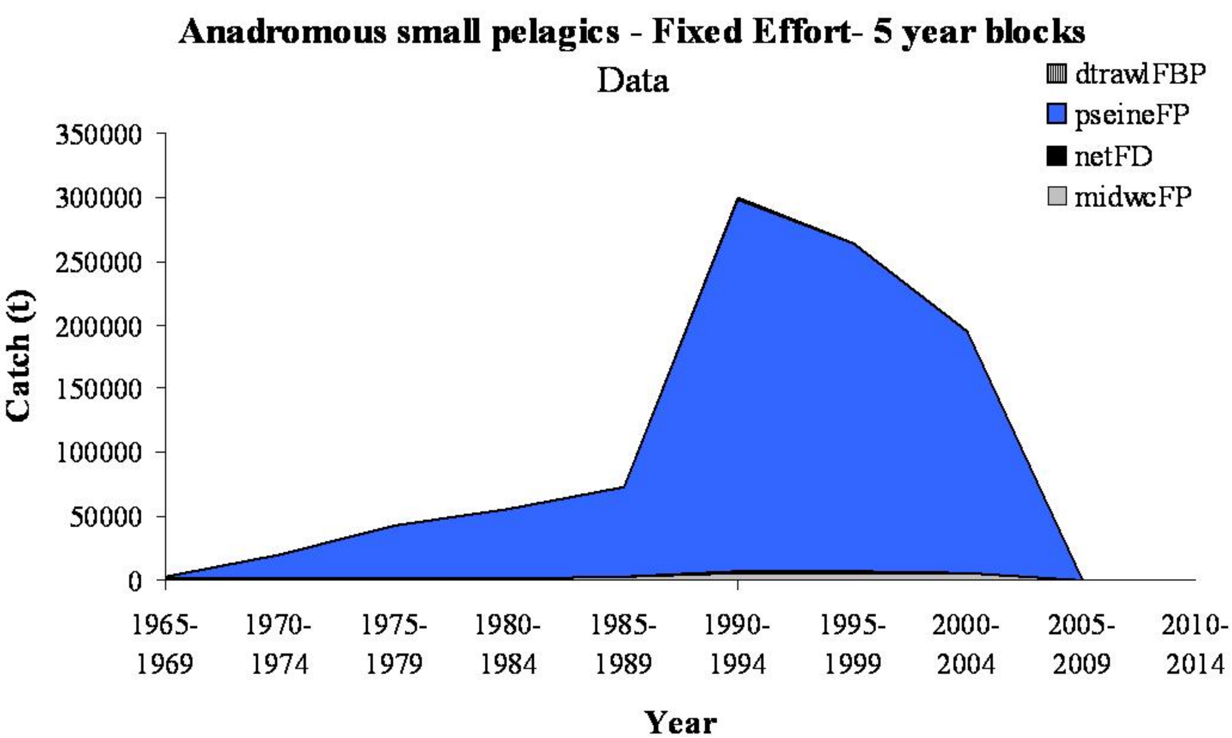
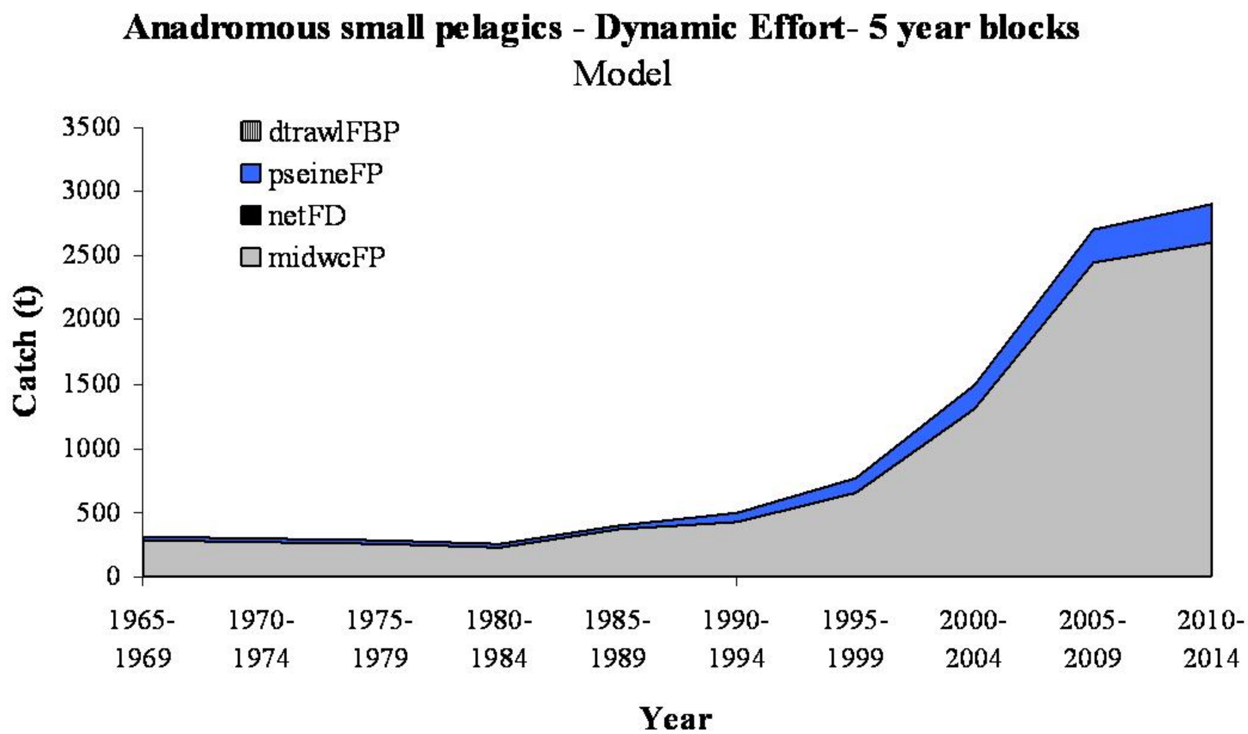


Figure D17. Anadromous small pelagics catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



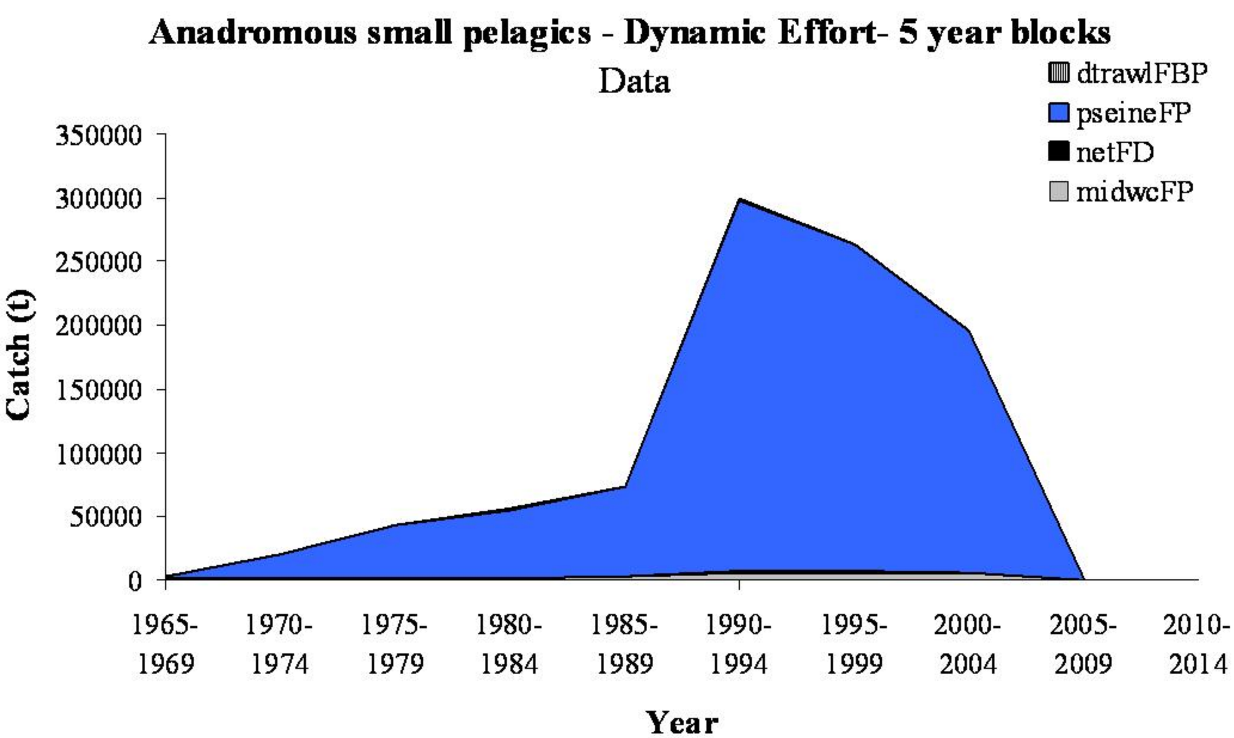
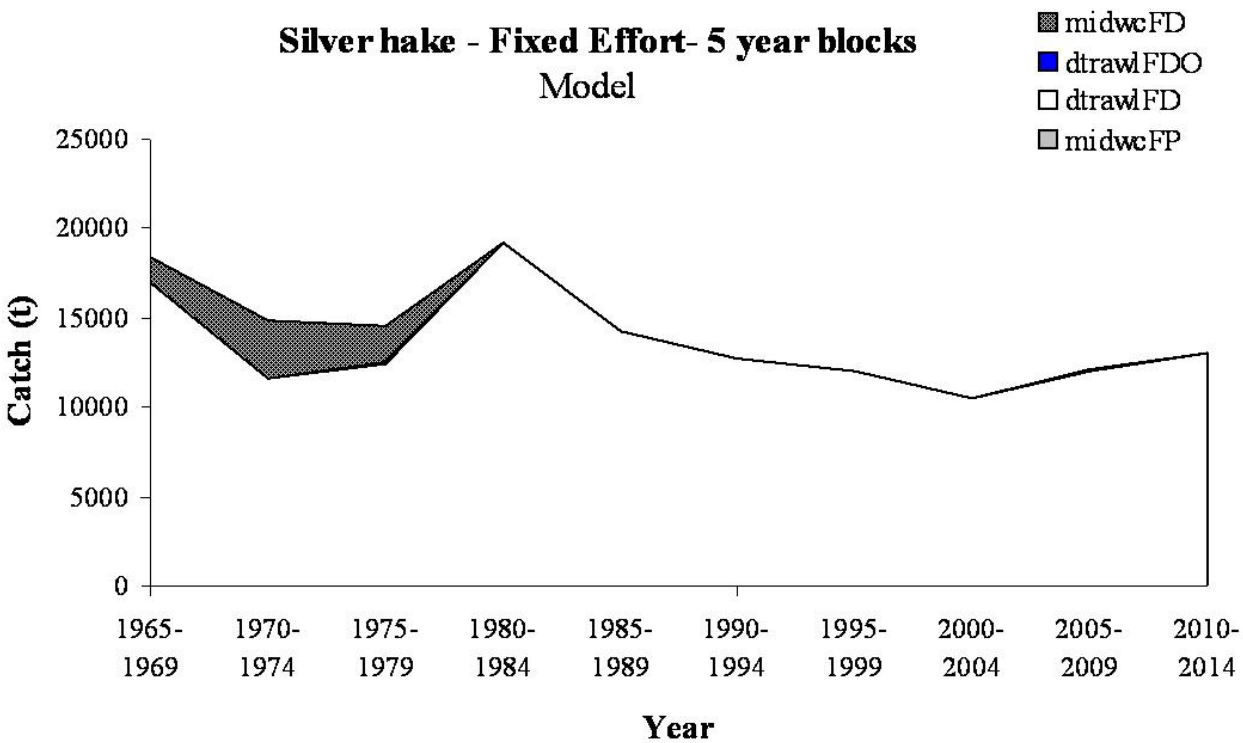


Figure D18. Anadromous small pelagics catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



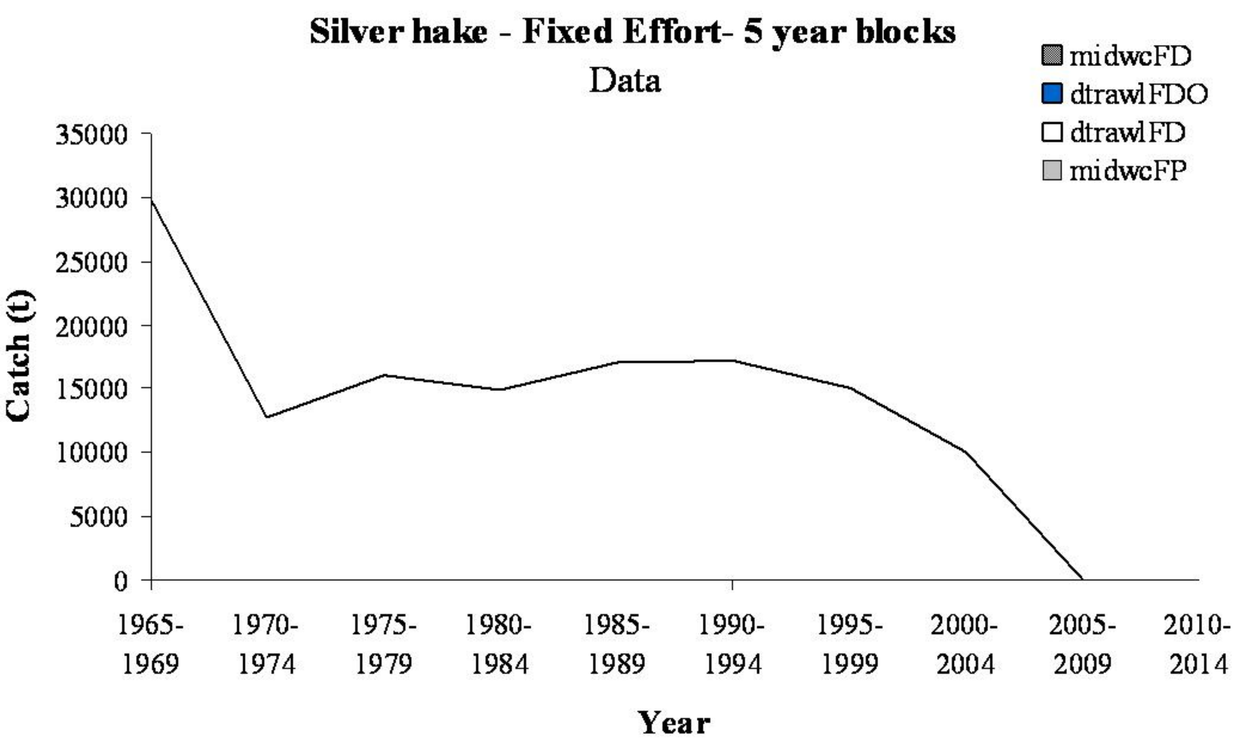
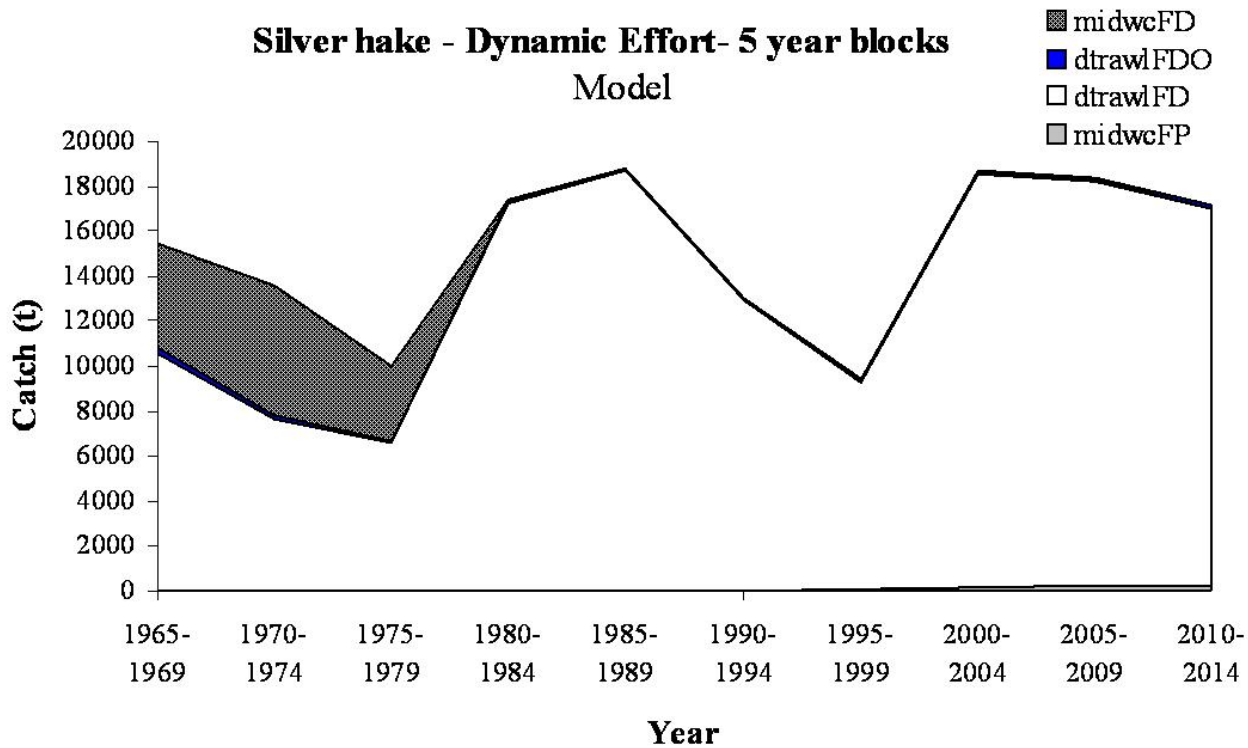


Figure D19. Silver hake (*Merluccius bilinearis*) catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



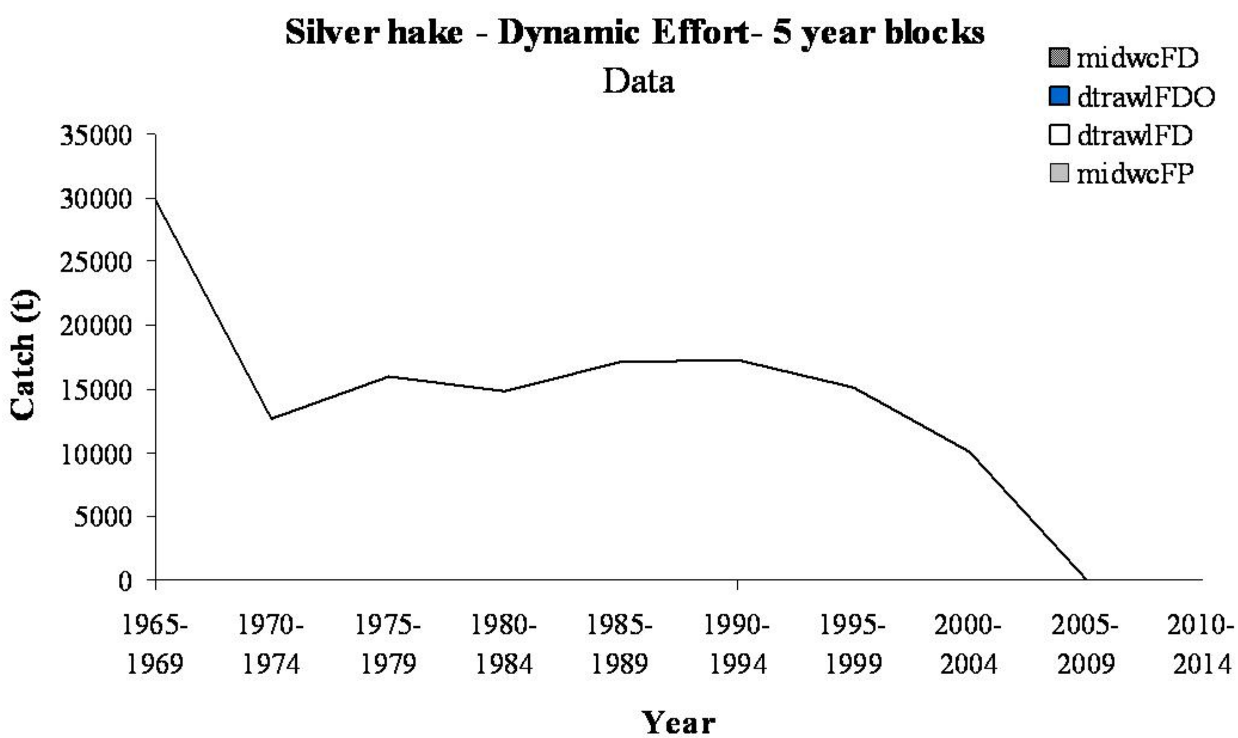
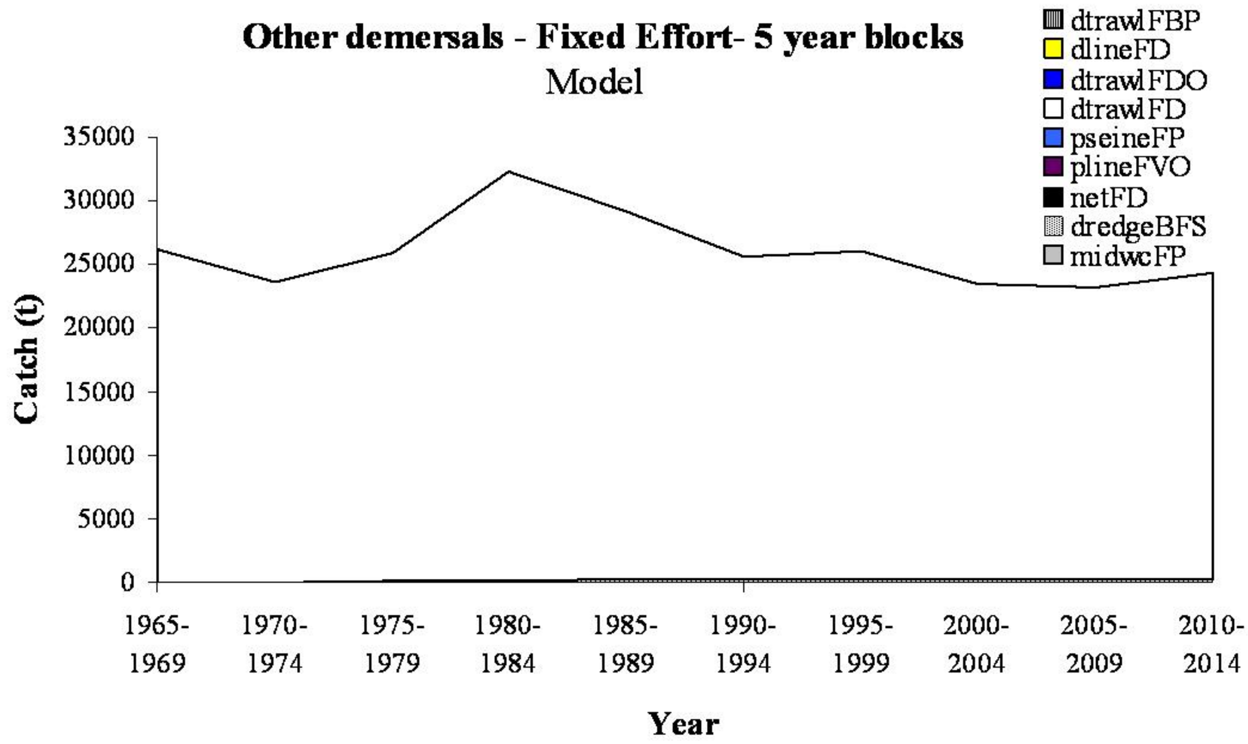


Figure D20. Silver hake (*Merluccius bilinearis*) catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



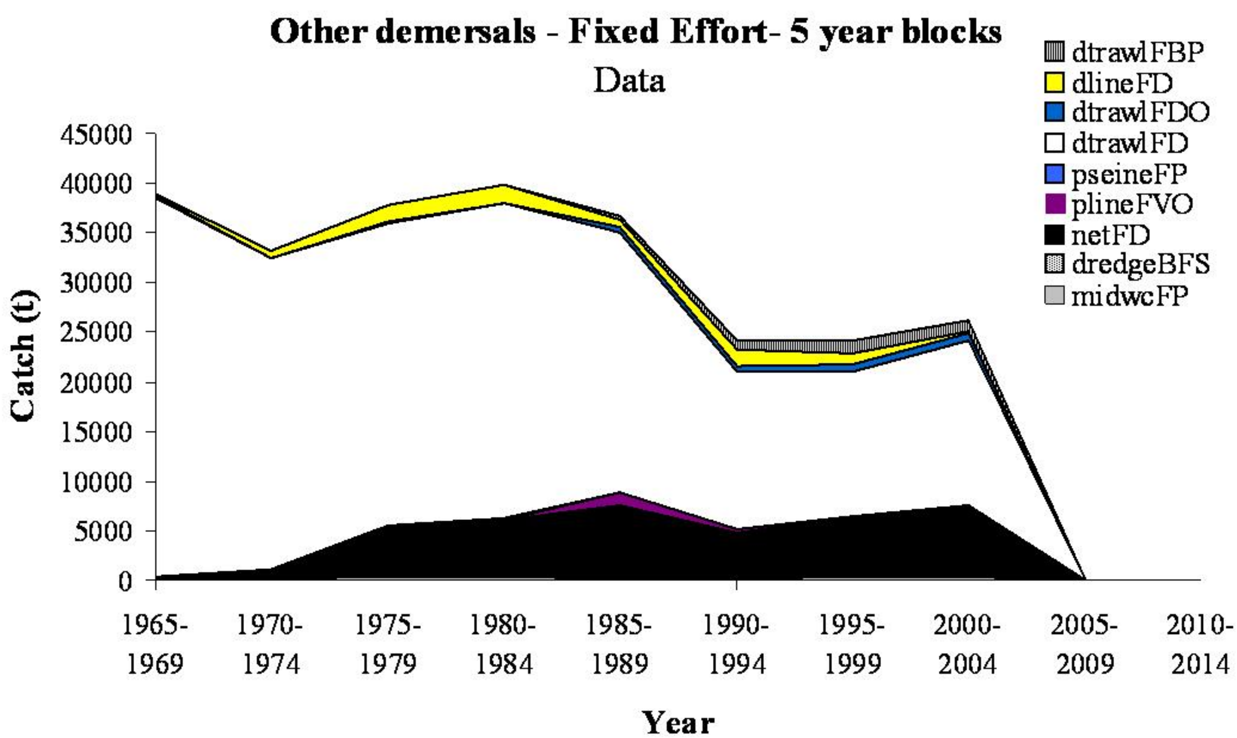
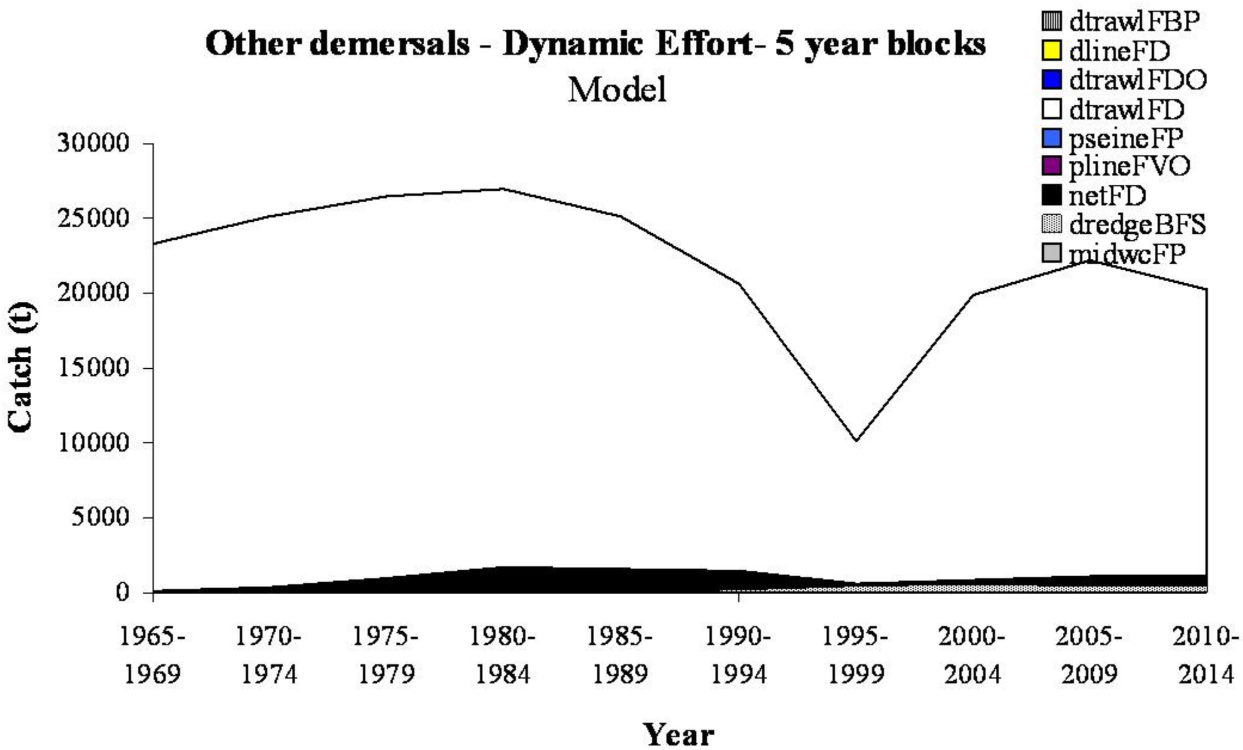


Figure D21. Other demersals catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



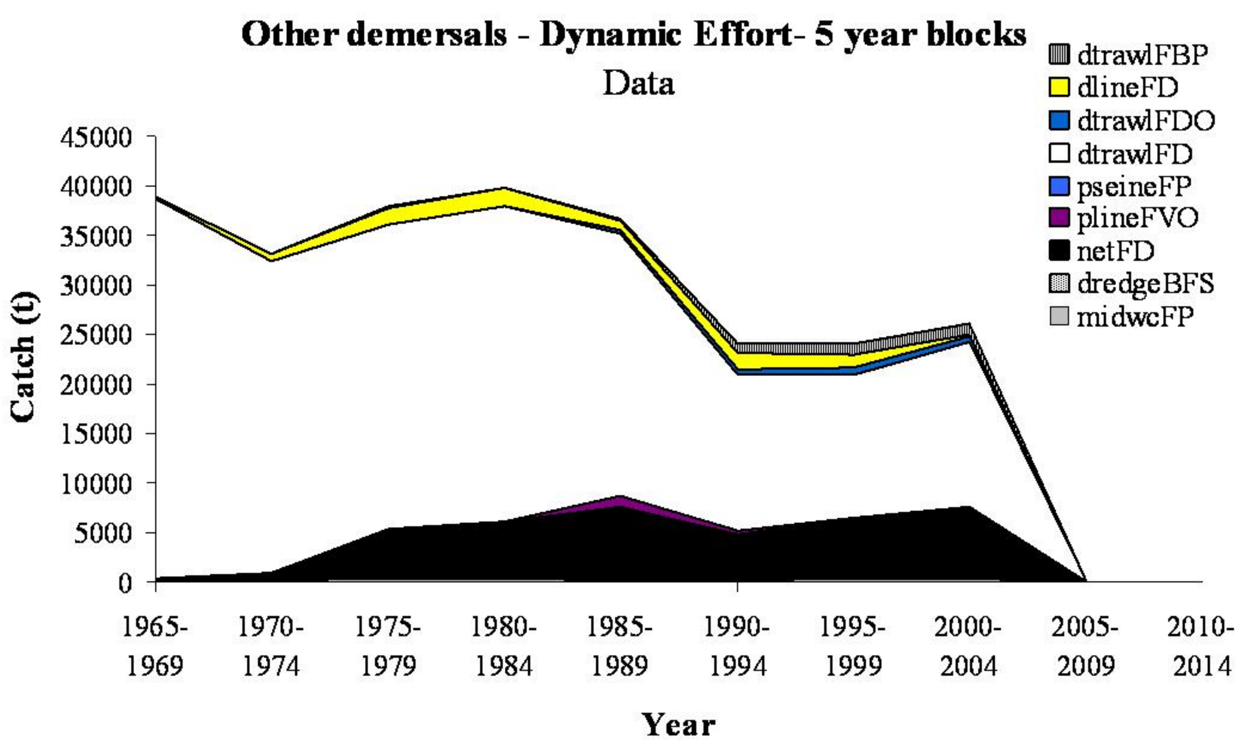
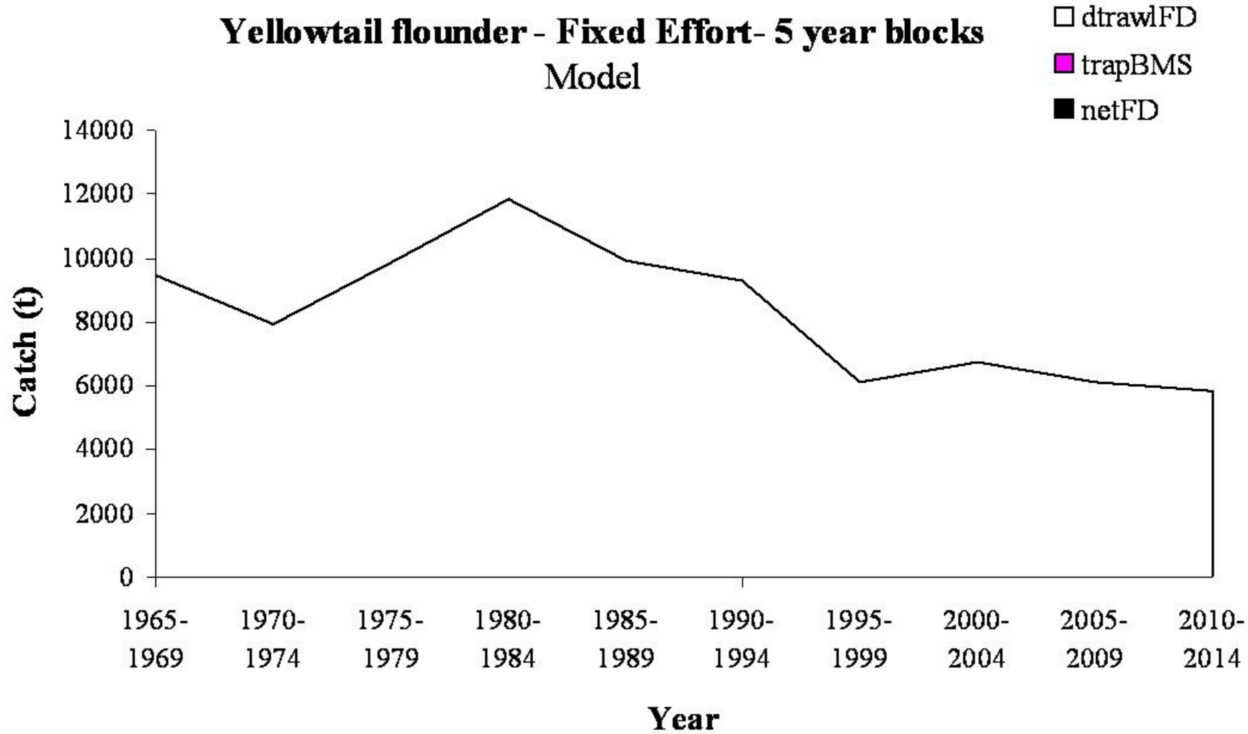


Figure D22. Other demersals catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



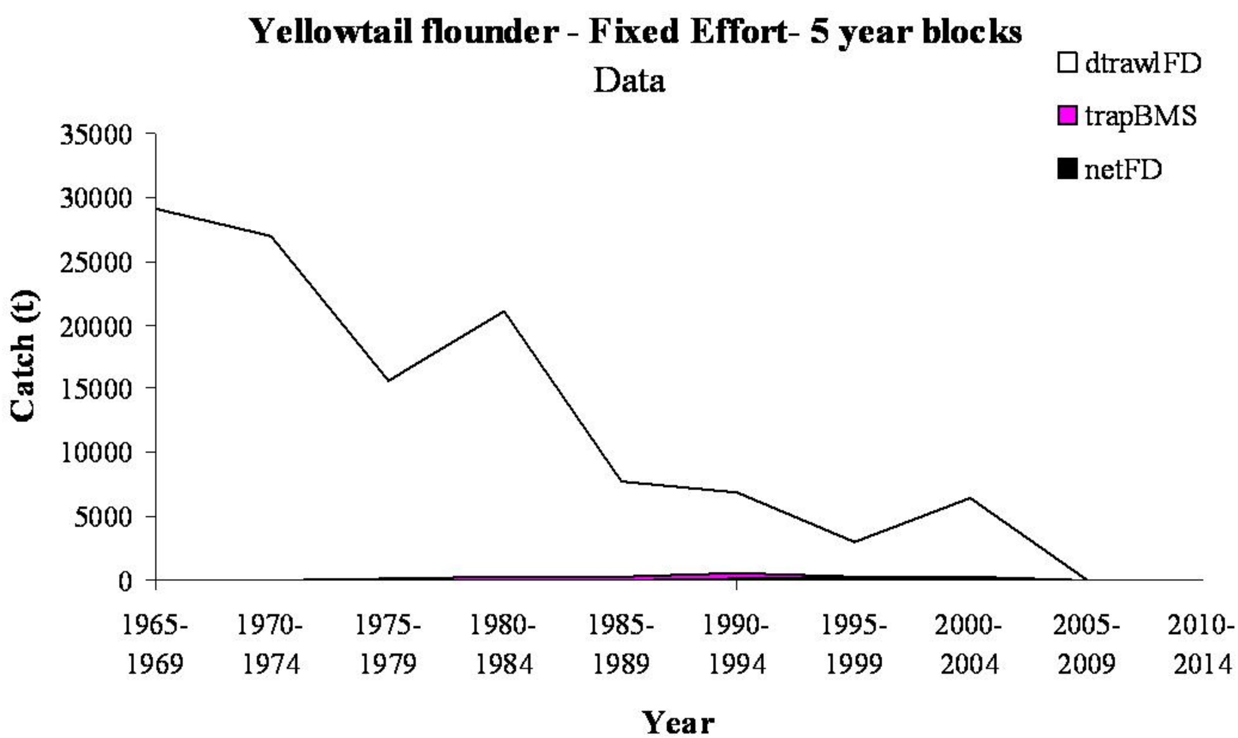
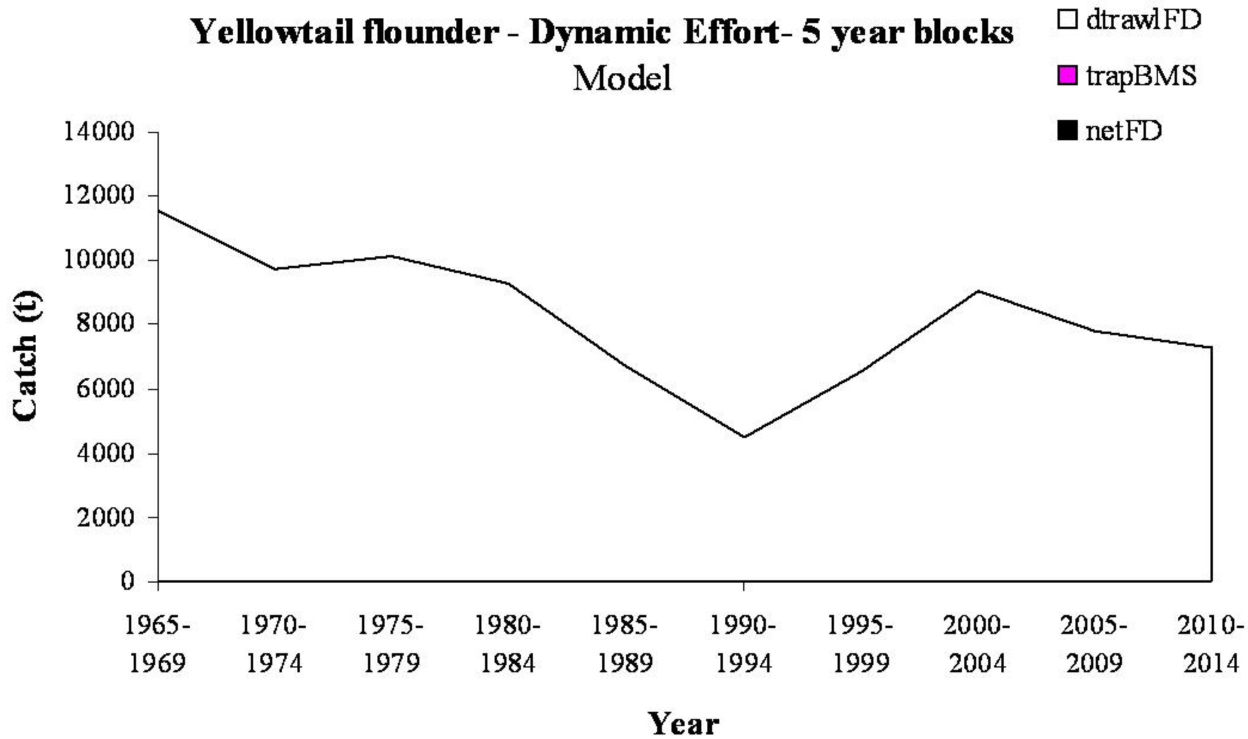


Figure D23. Yellowtail flounder (*Limanda ferruginea*) catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



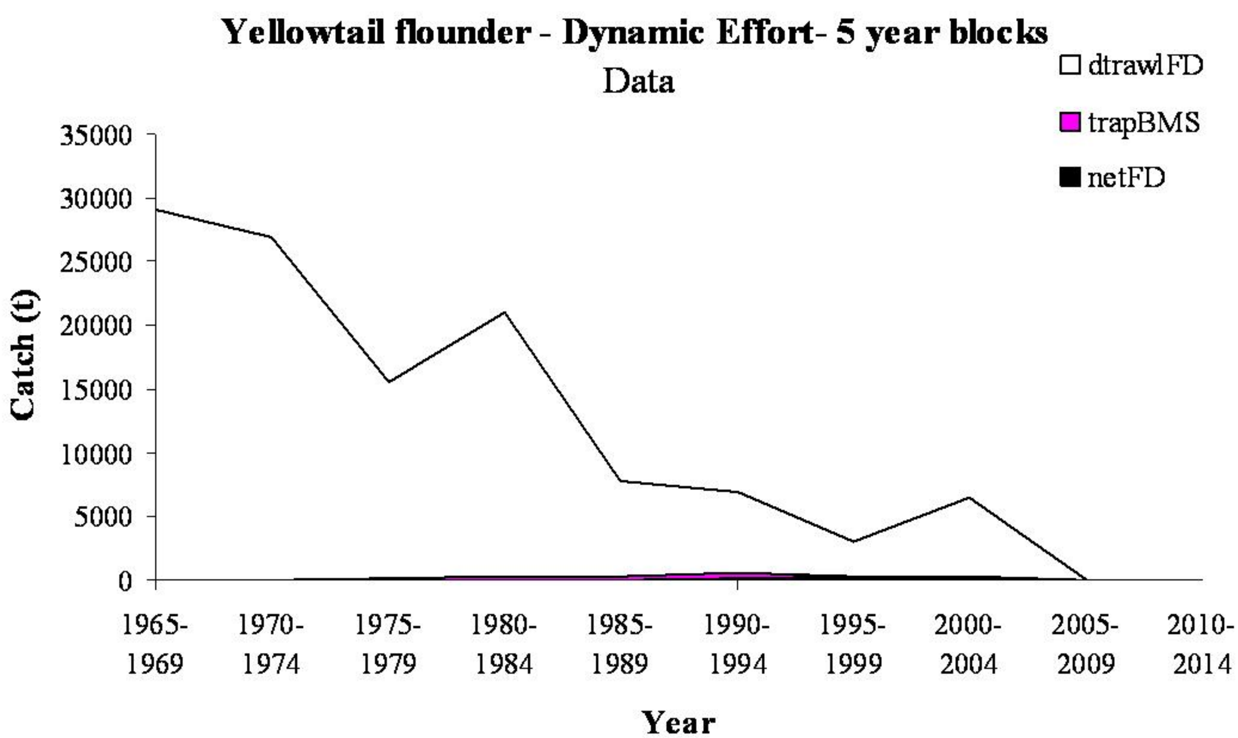
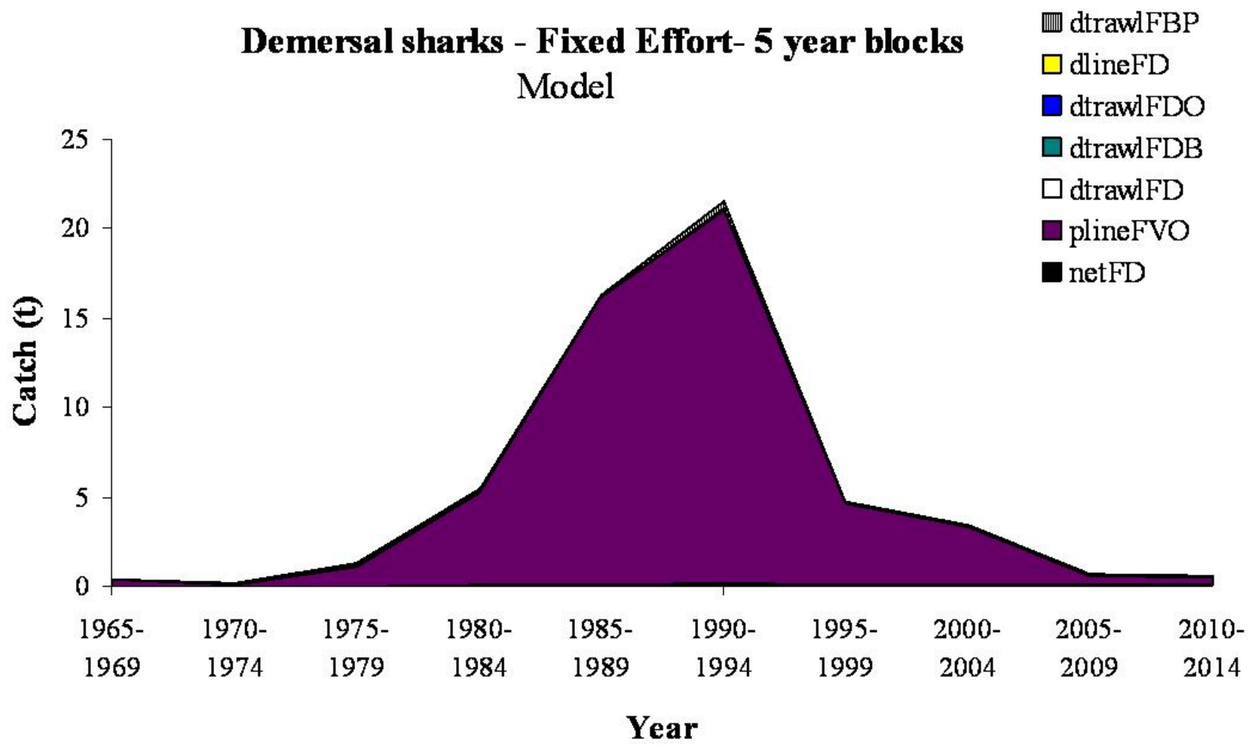


Figure D24. Yellowtail flounder (*Limanda ferruginea*) catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



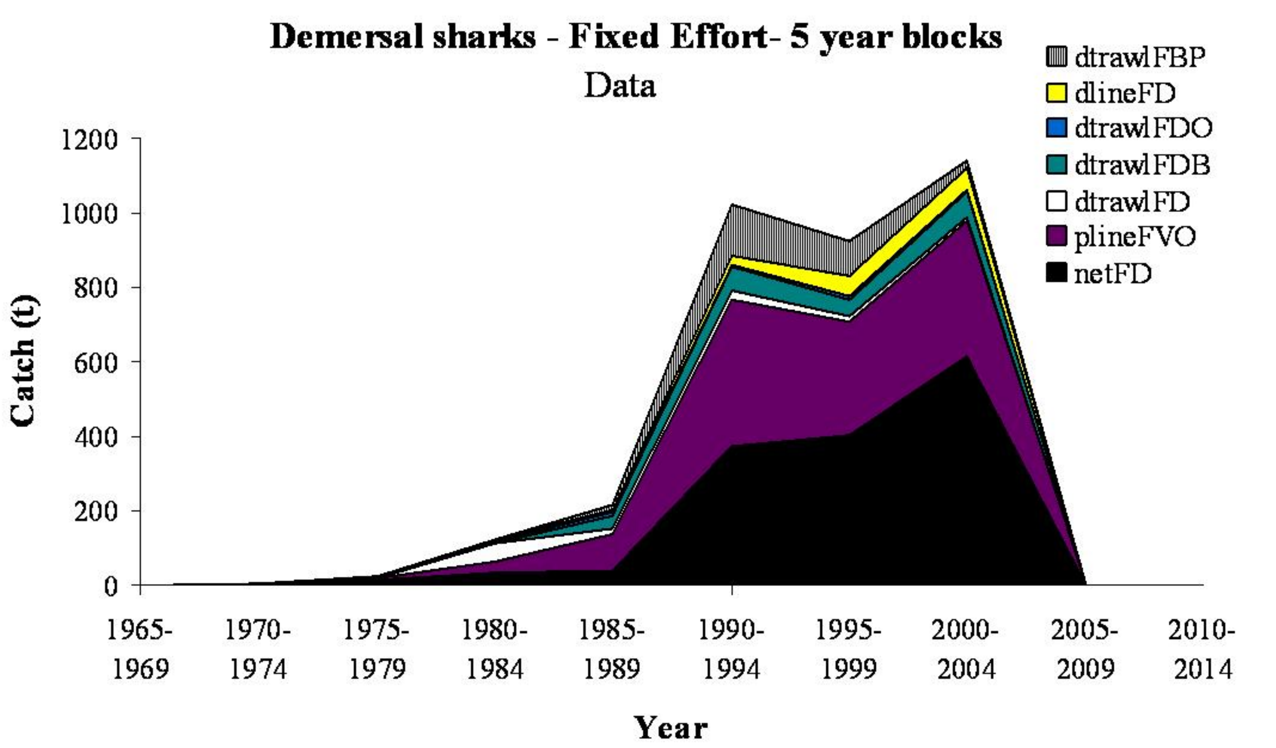
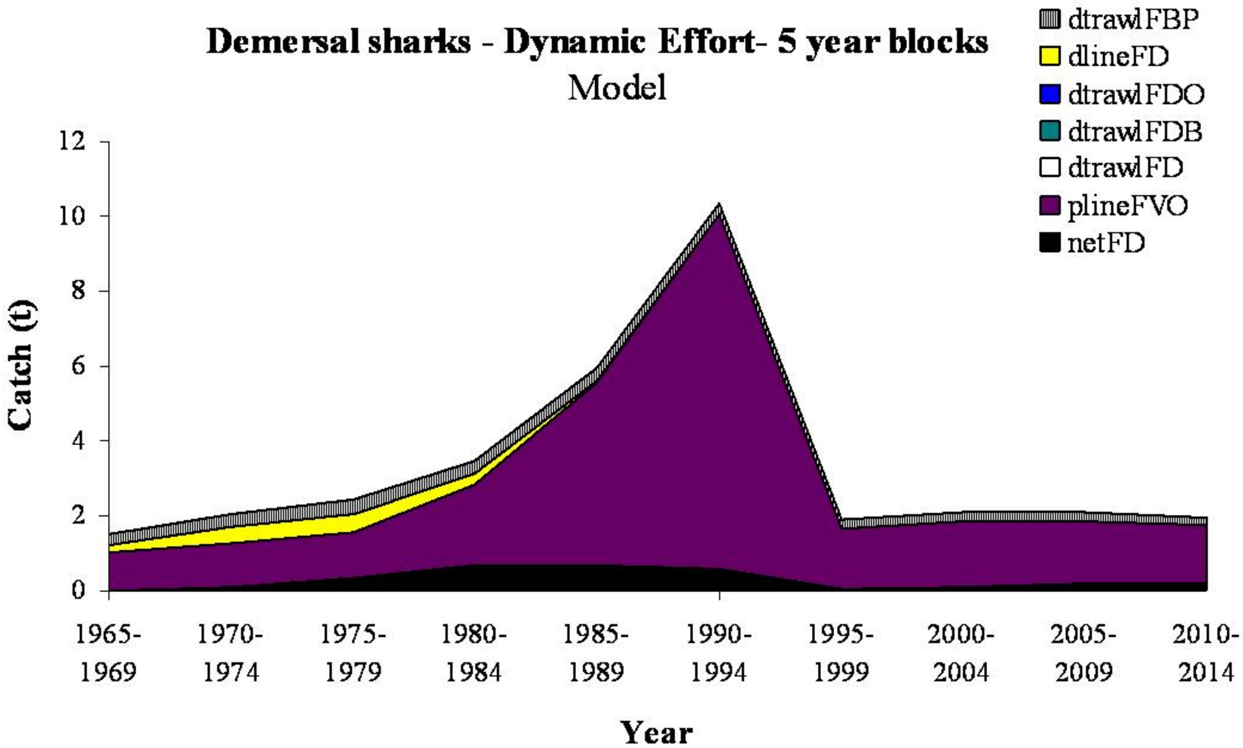


Figure D25. Demersal sharks catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



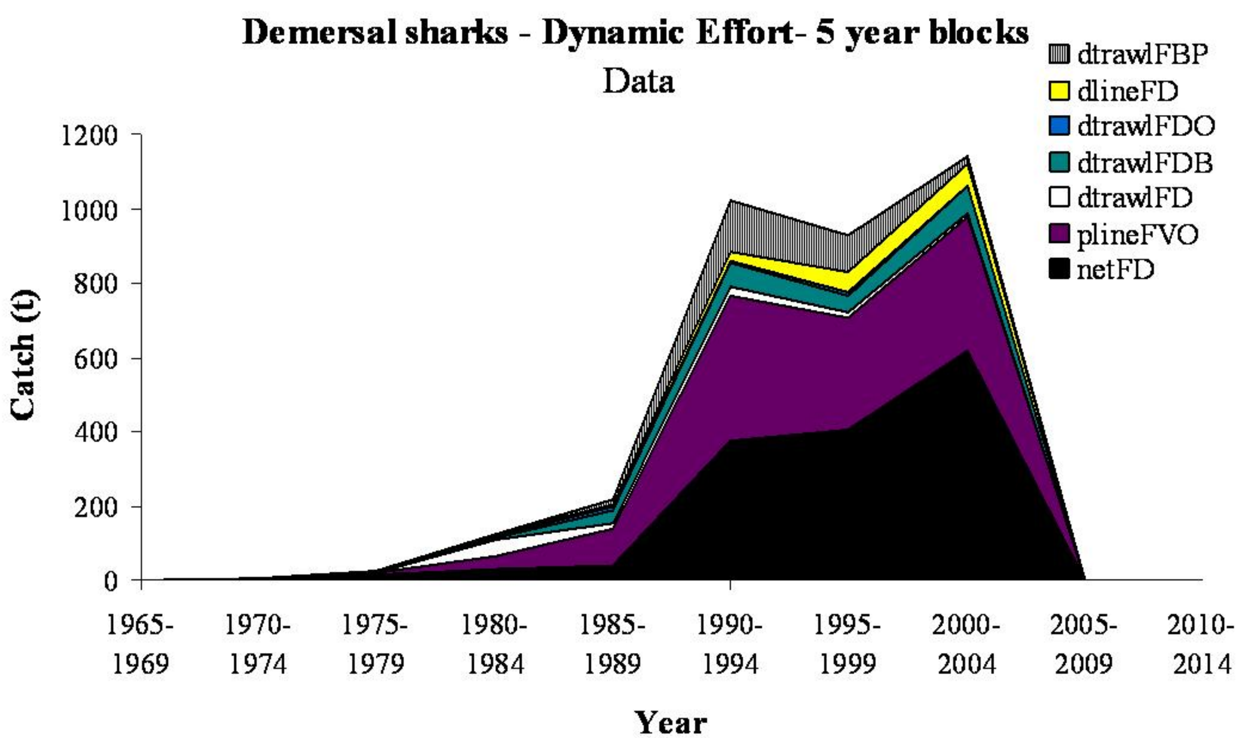


Figure D26. Demersal sharks catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

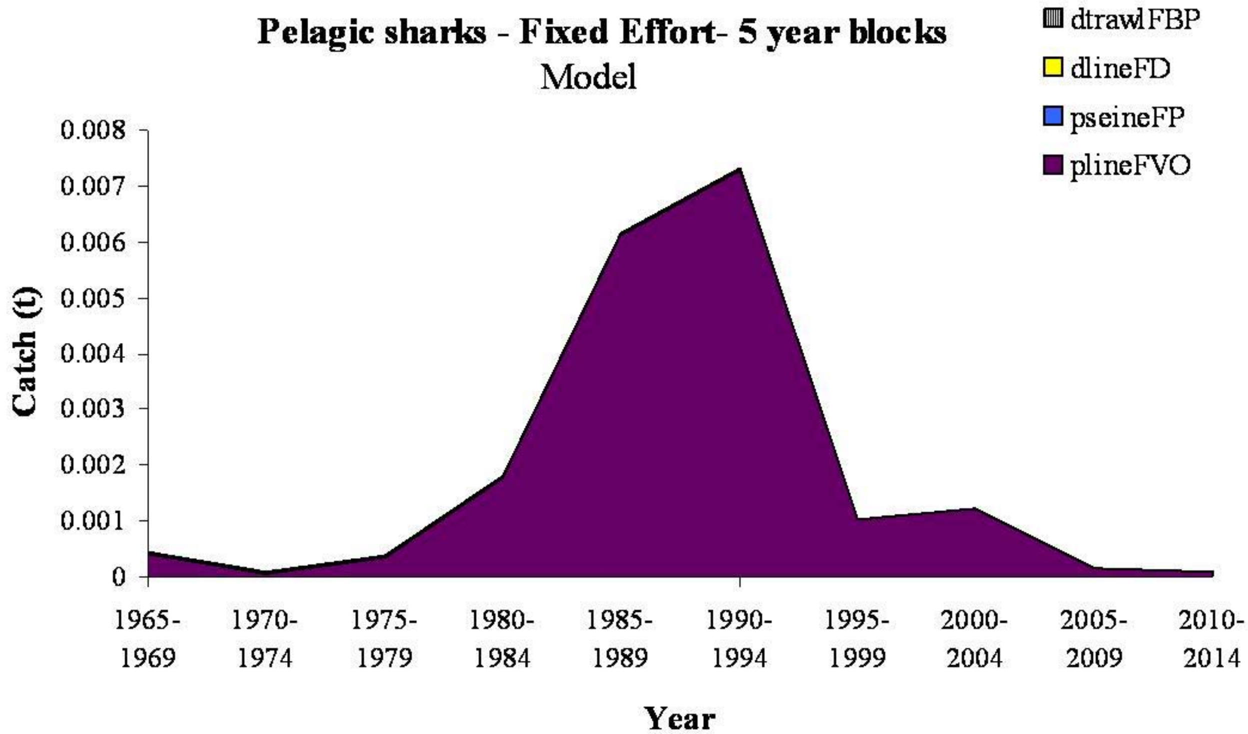


Figure D27. Pelagic sharks catch per fishery trajectory for Atlantis NEUS (fixed effort run). No observed time series was available.

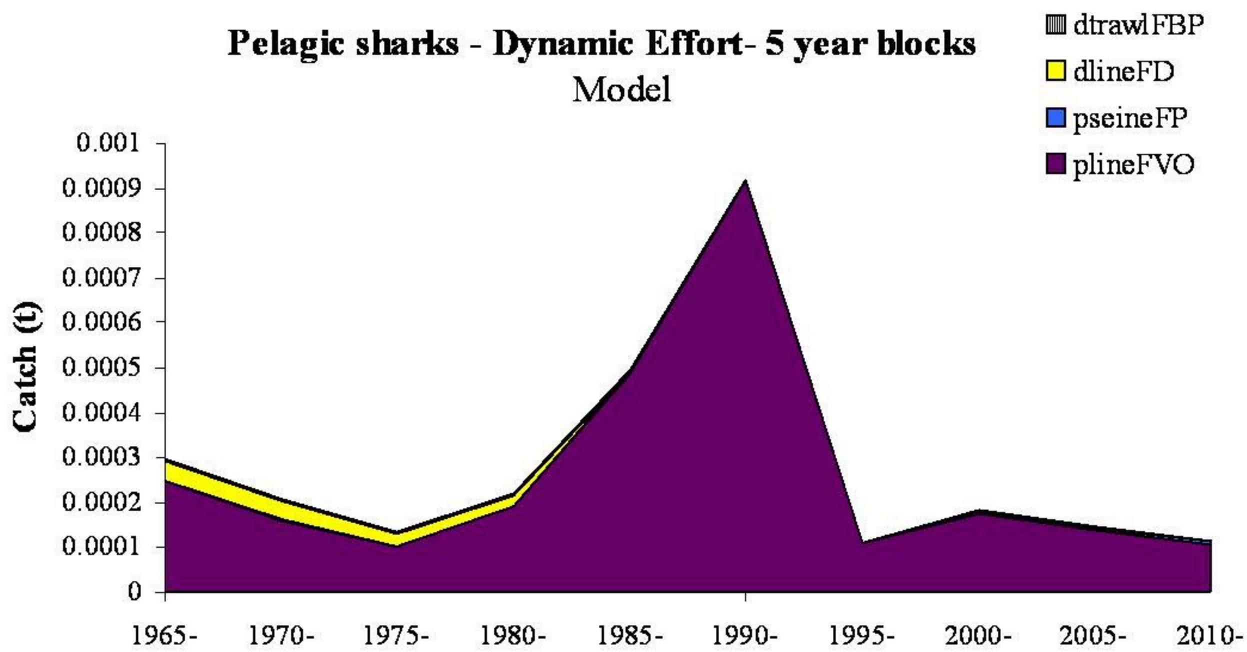
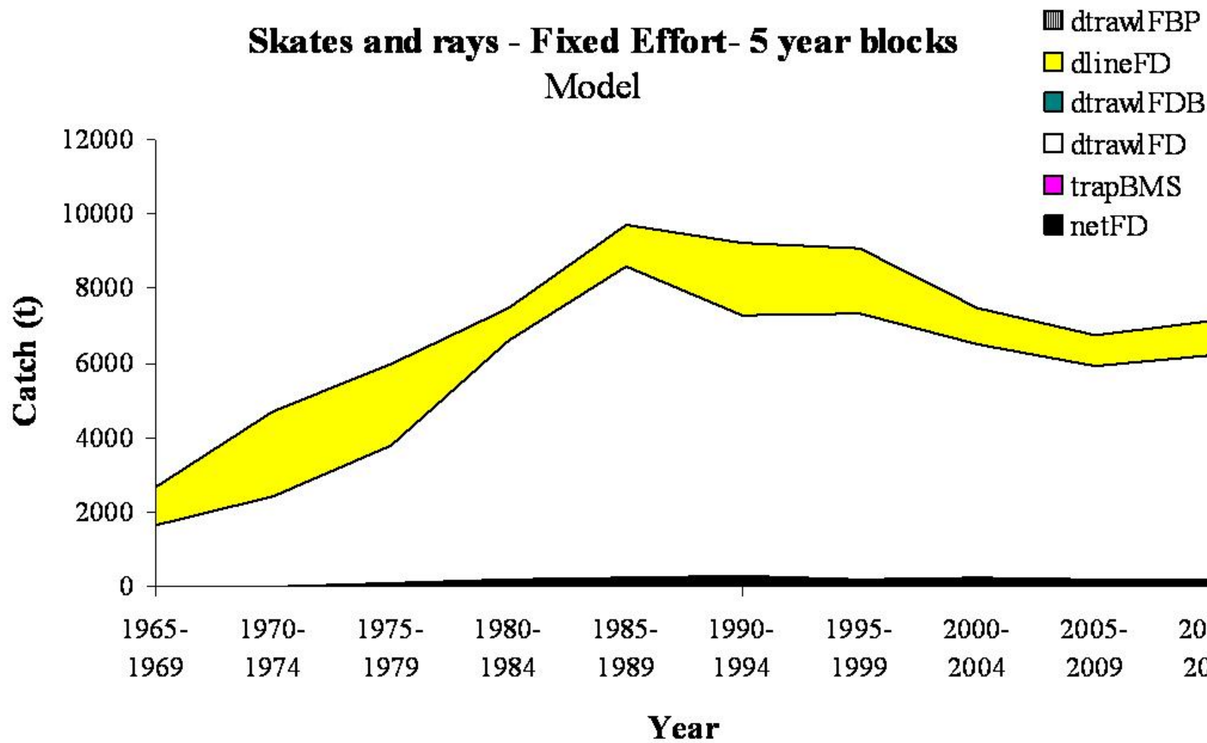


Figure D28. Pelagic sharks catch per fishery trajectory for Atlantis NEUS (dynamic effort run). No observed time series was available.



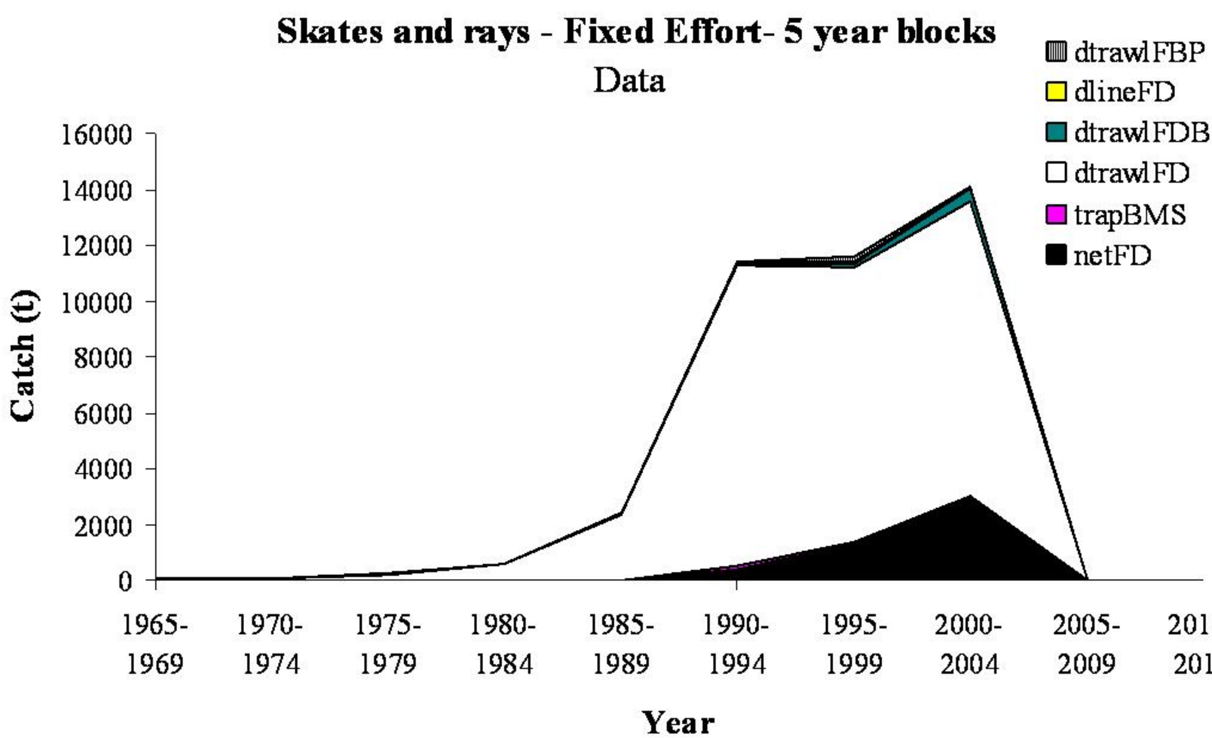
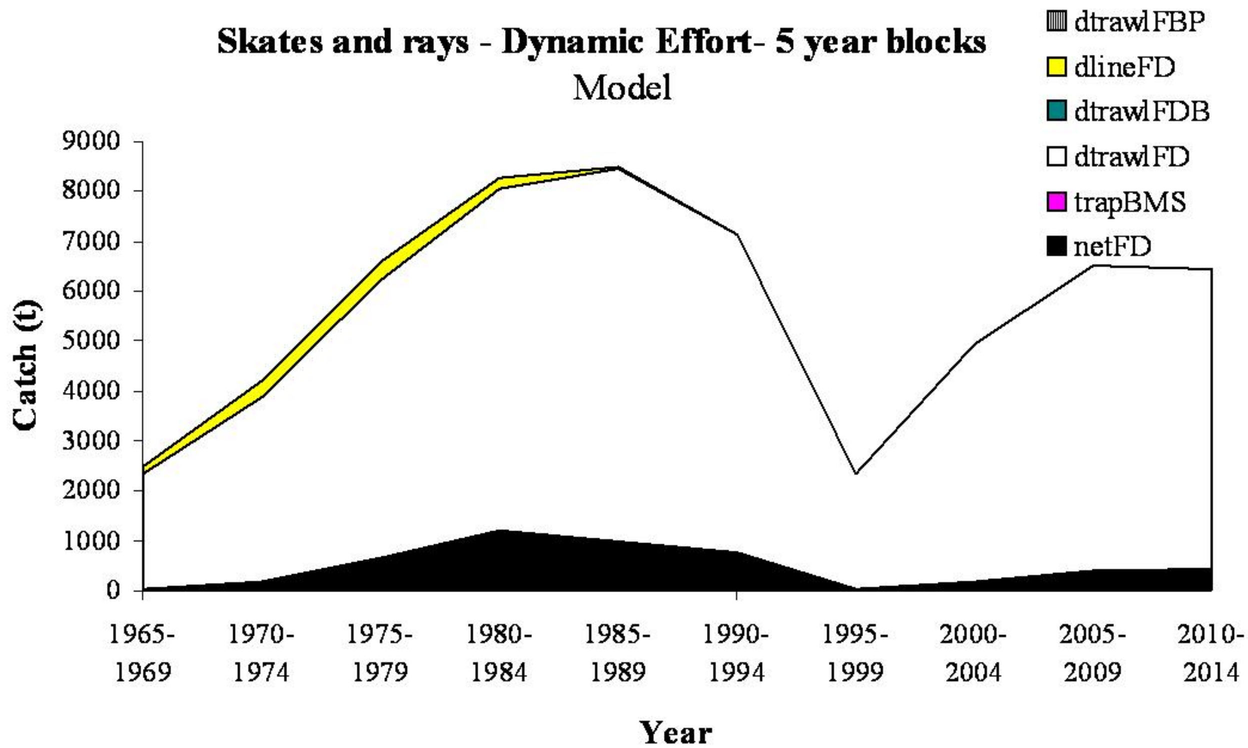


Figure D29. Skates and rays catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



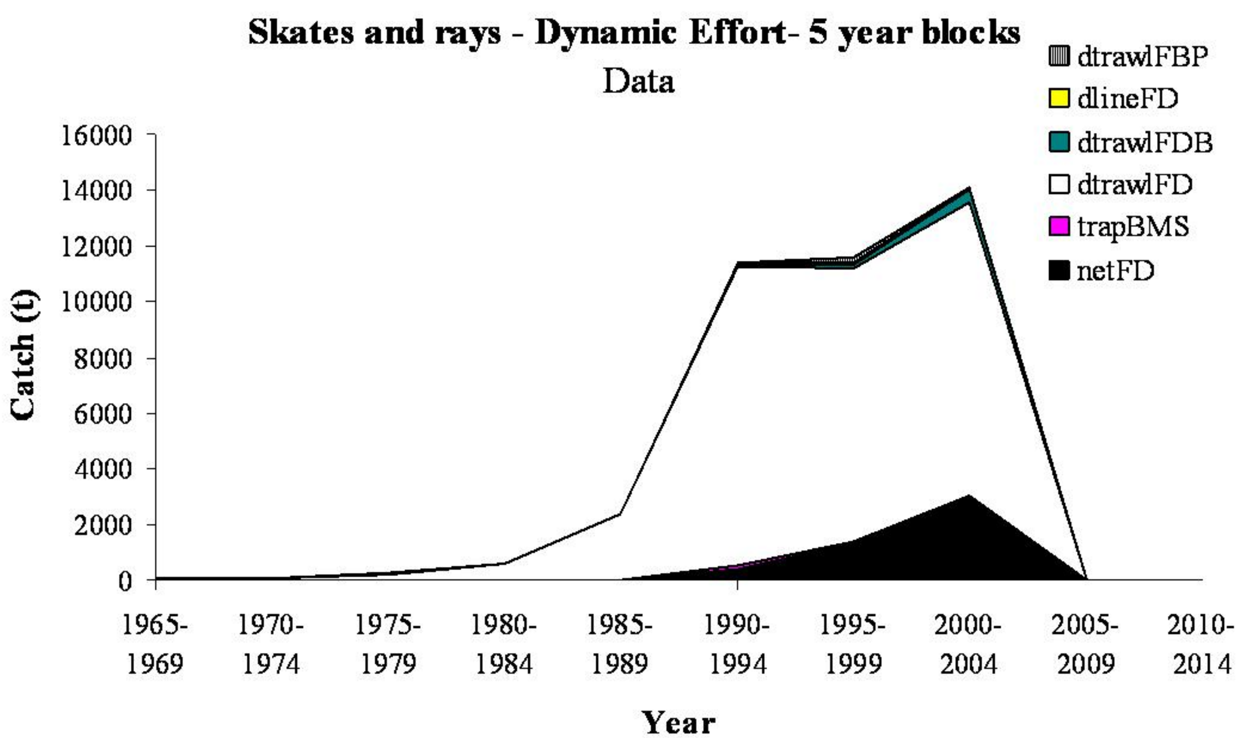
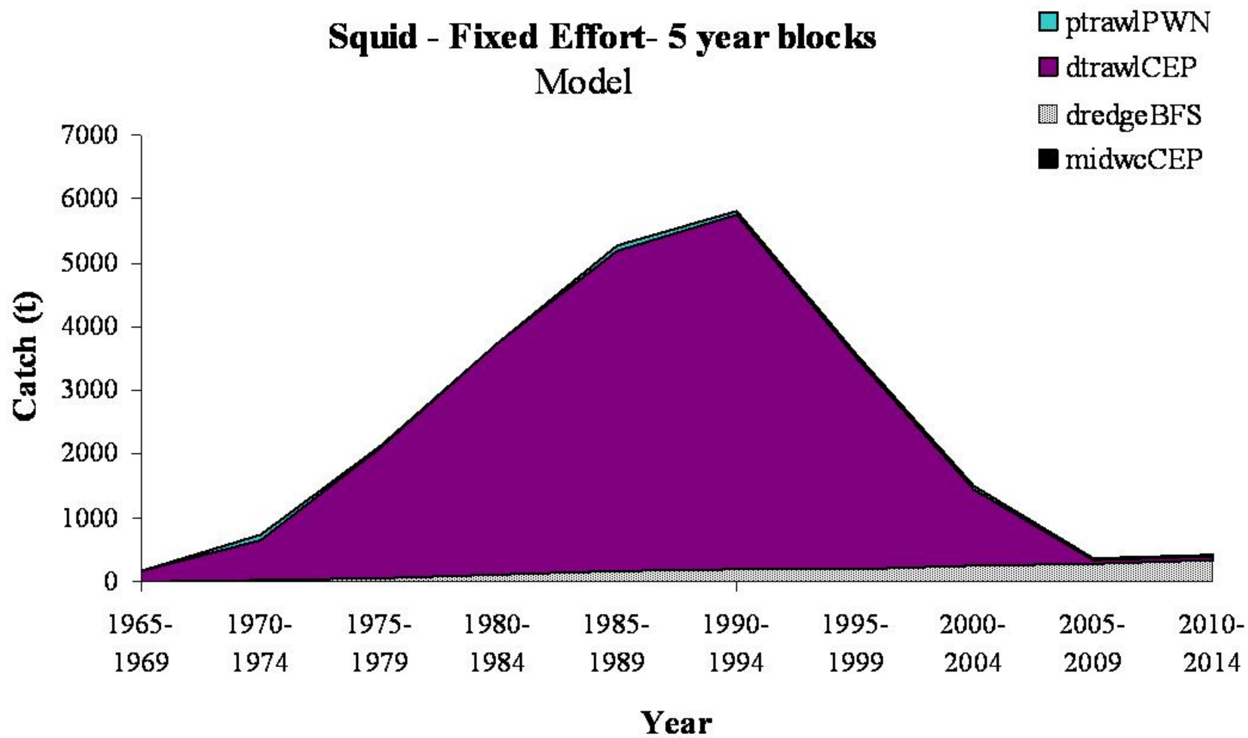


Figure D30. Skates and rays catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



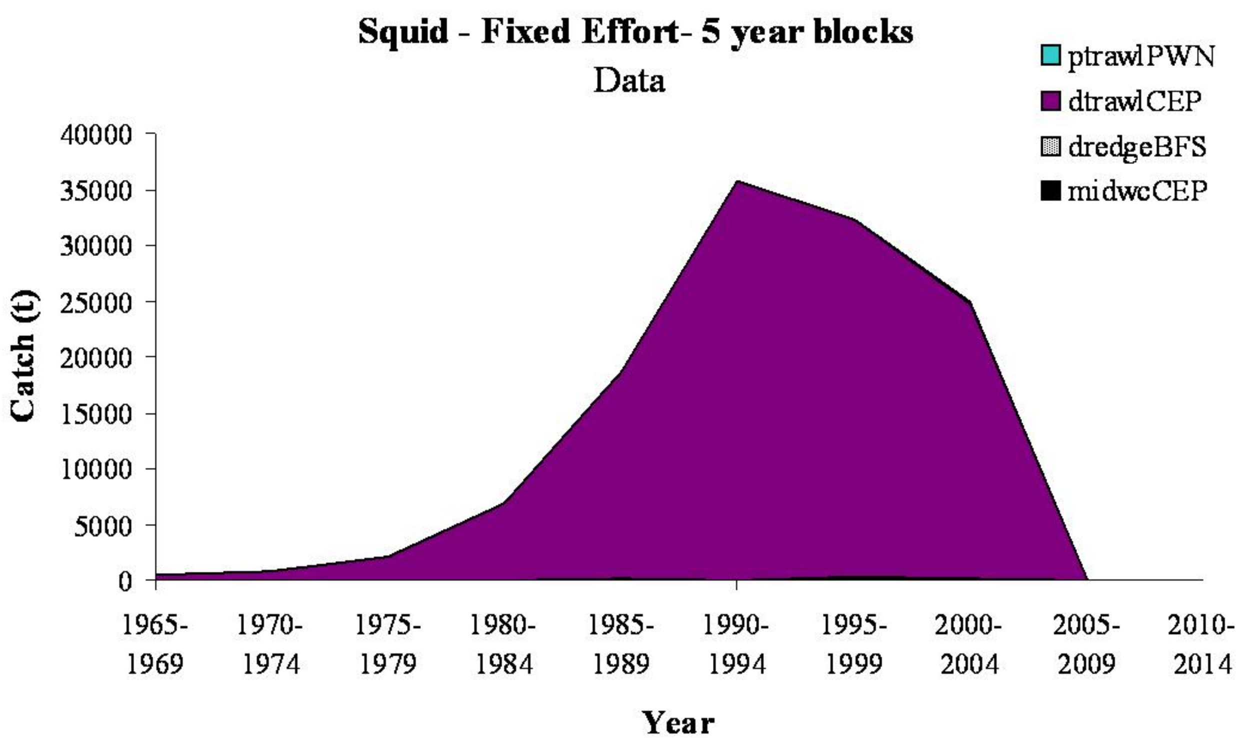


Figure D31. Squid catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.

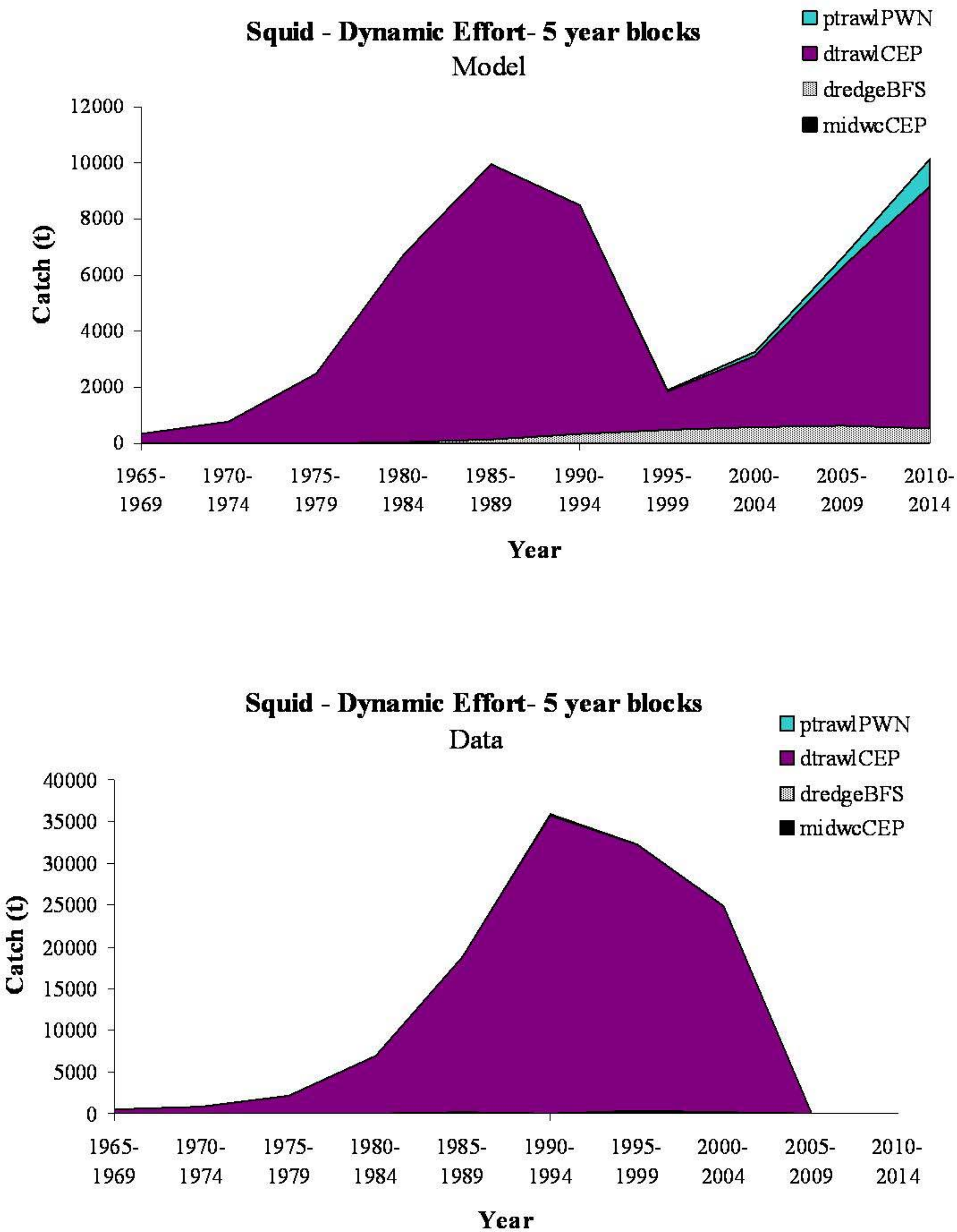
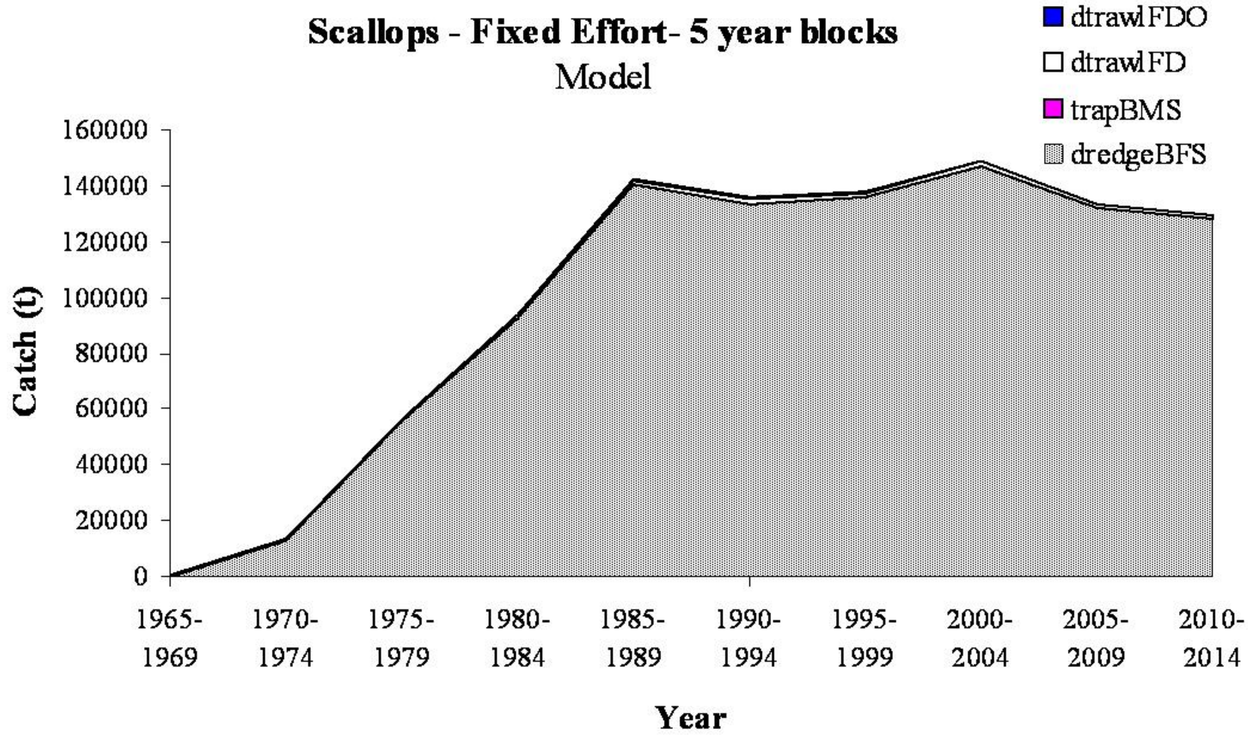


Figure D32. Squid catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



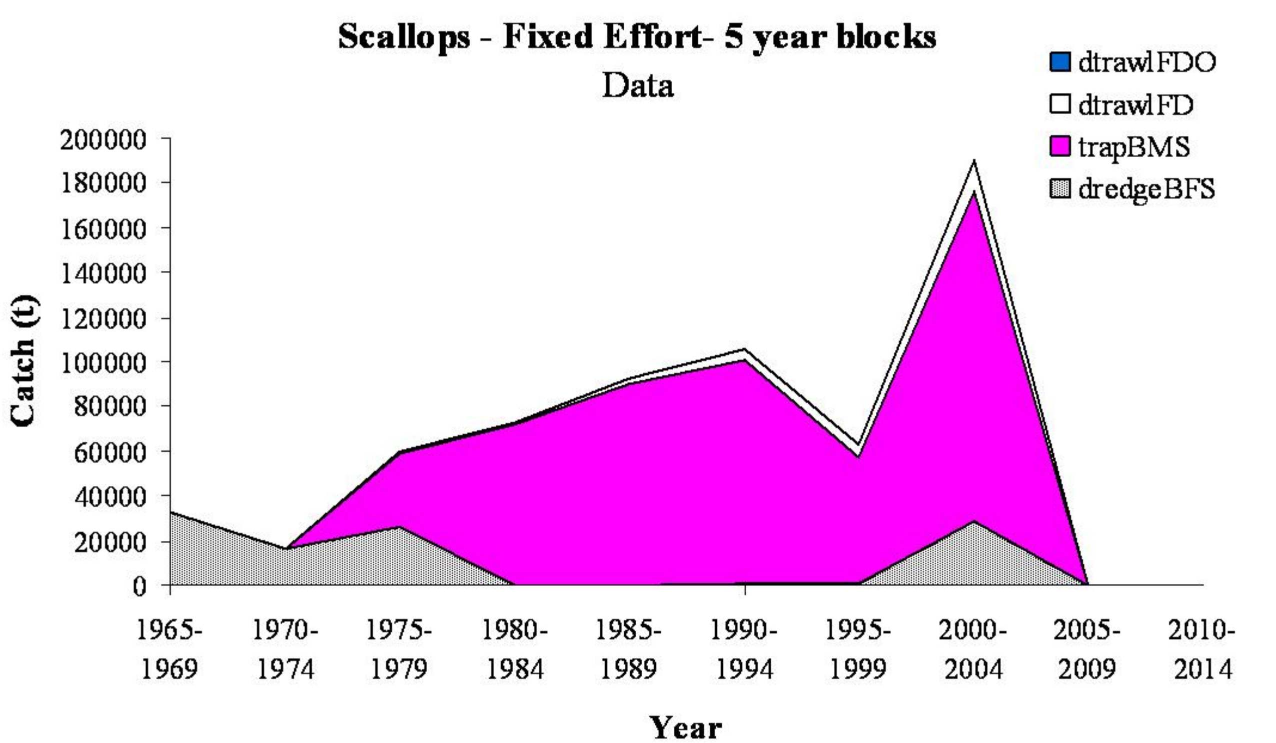
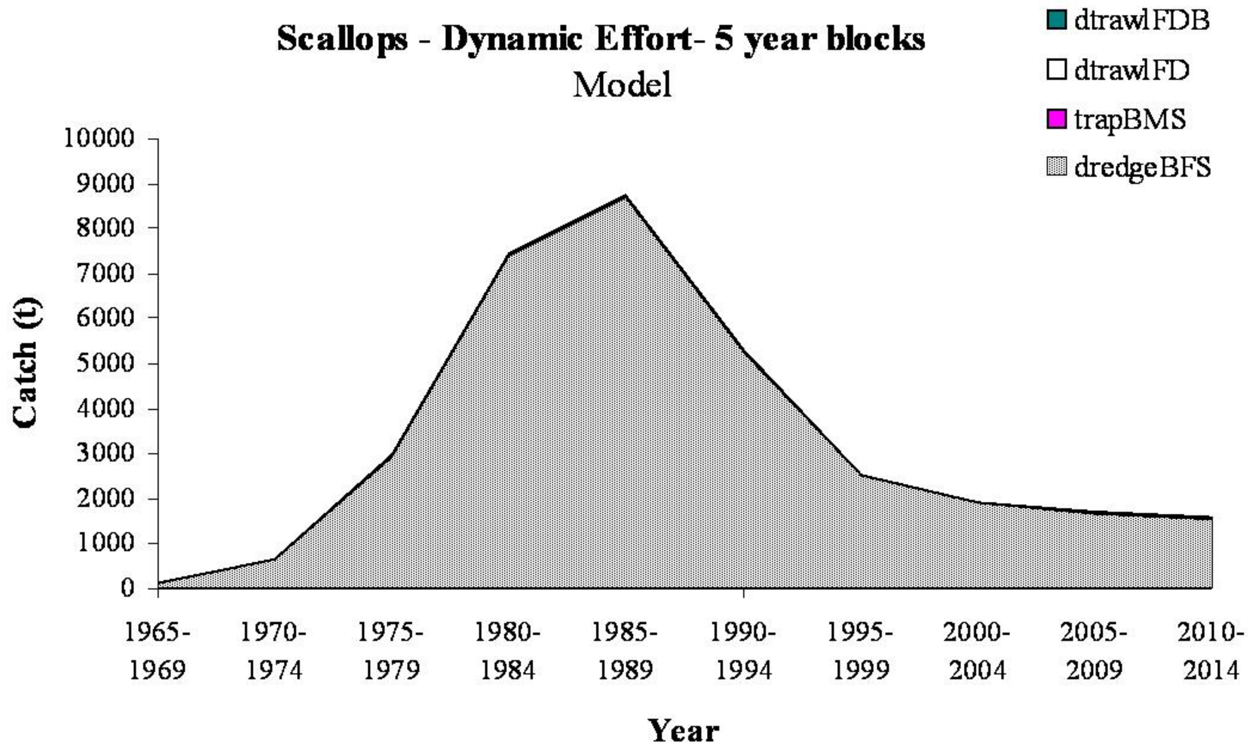


Figure D33. Sea scallops (*Placopecten magellanicus*) catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



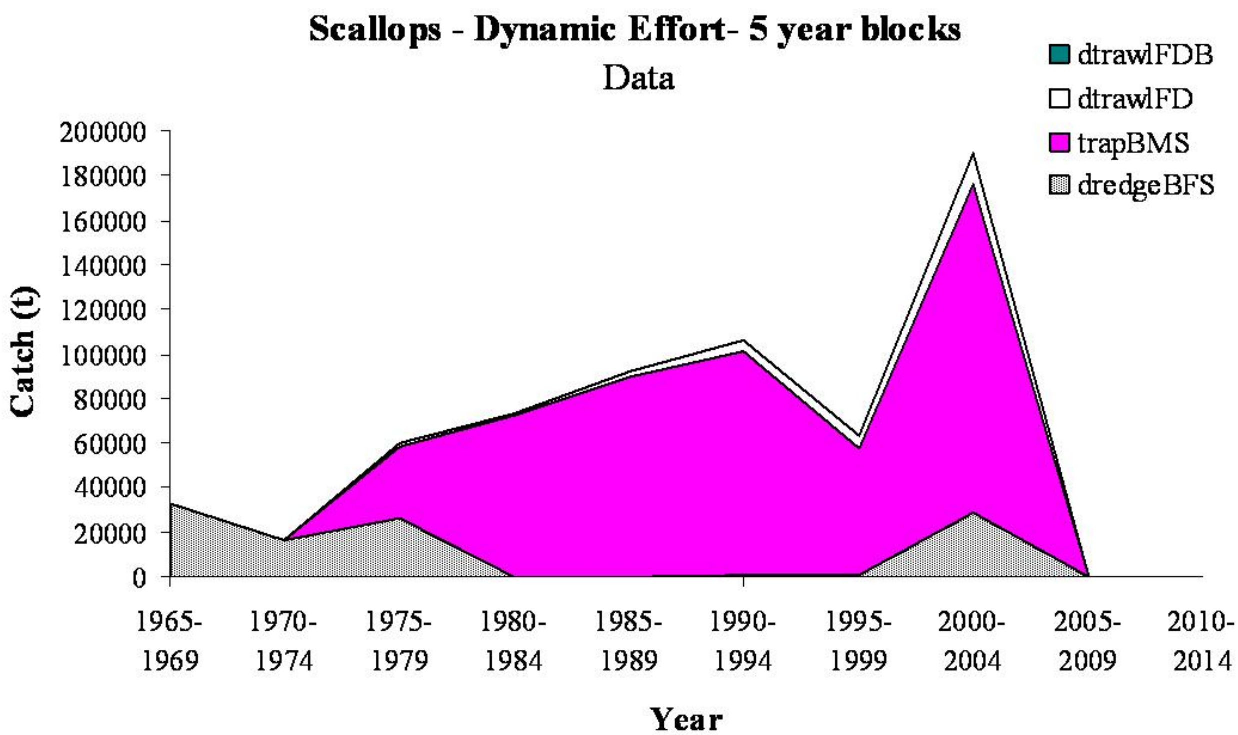


Figure D34. Sea scallops (*Placopecten magellanicus*) catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

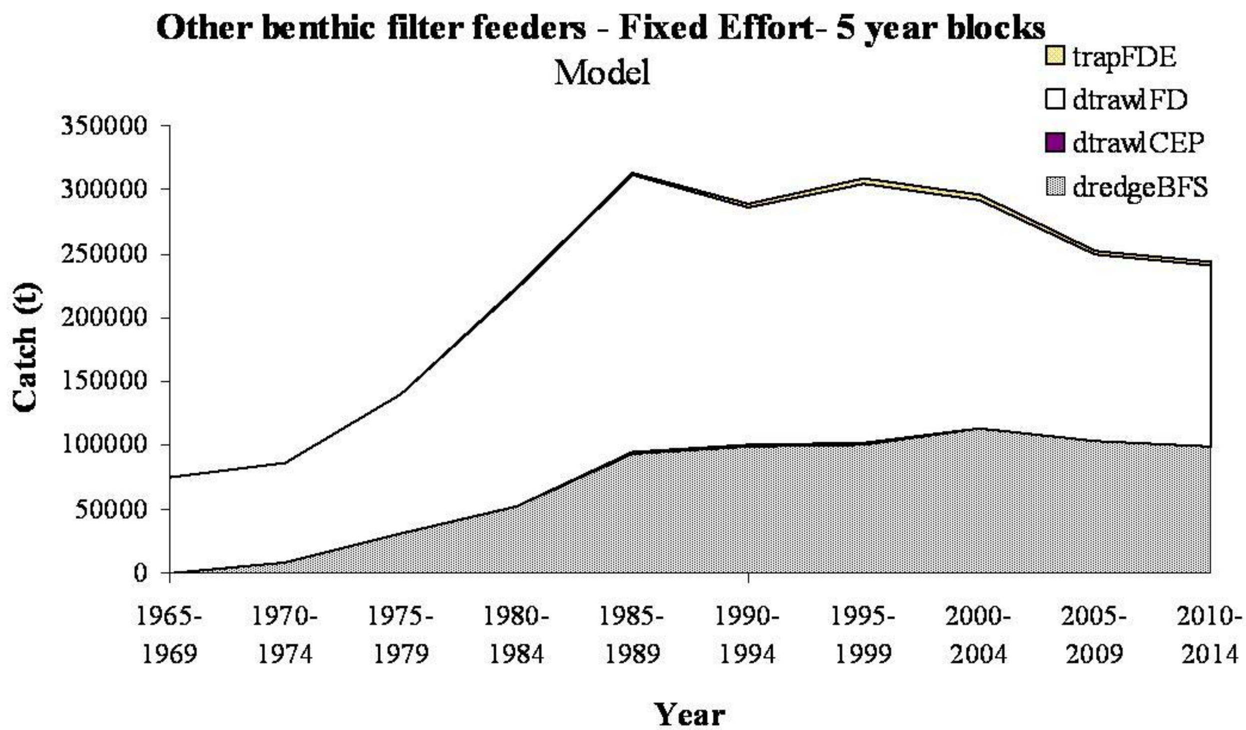


Figure D35. Other benthic filter feeders catch per fishery trajectory for Atlantis NEUS (fixed effort run). No observed time series was available.

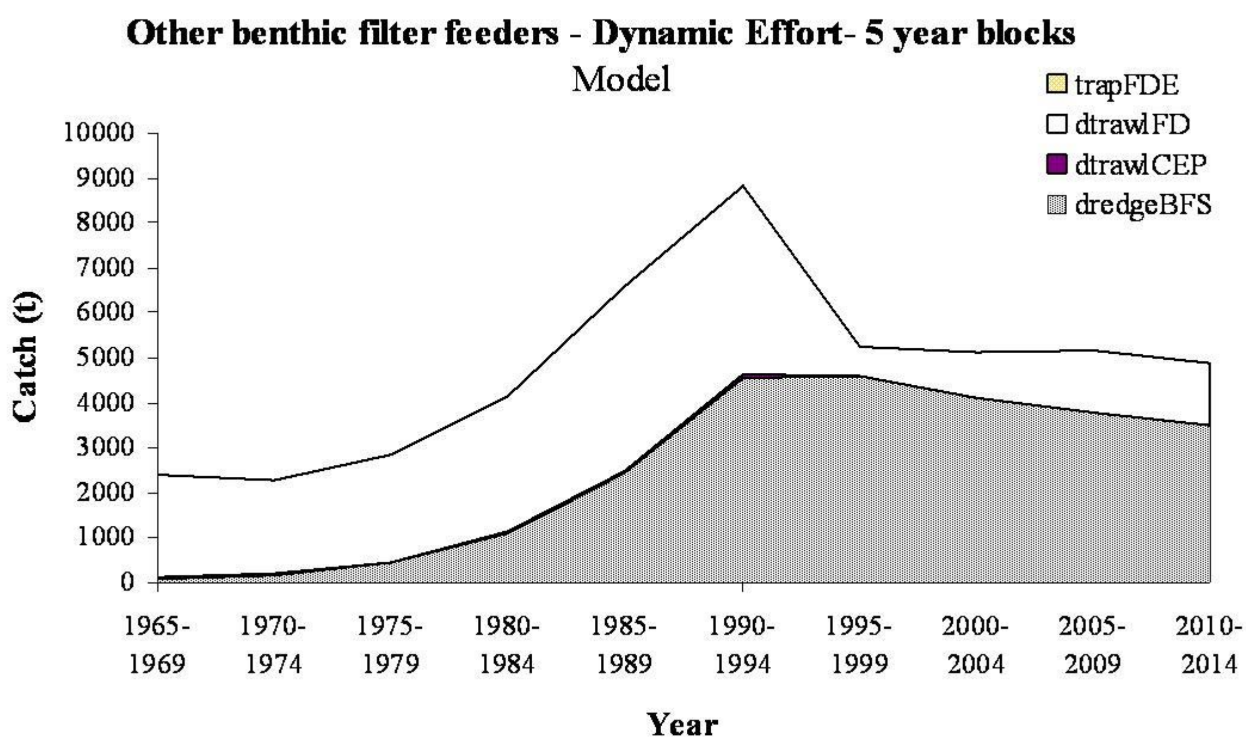


Figure D36. Other benthic filter feeders catch per fishery trajectory for Atlantis NEUS (dynamic effort run). No observed time series was available.

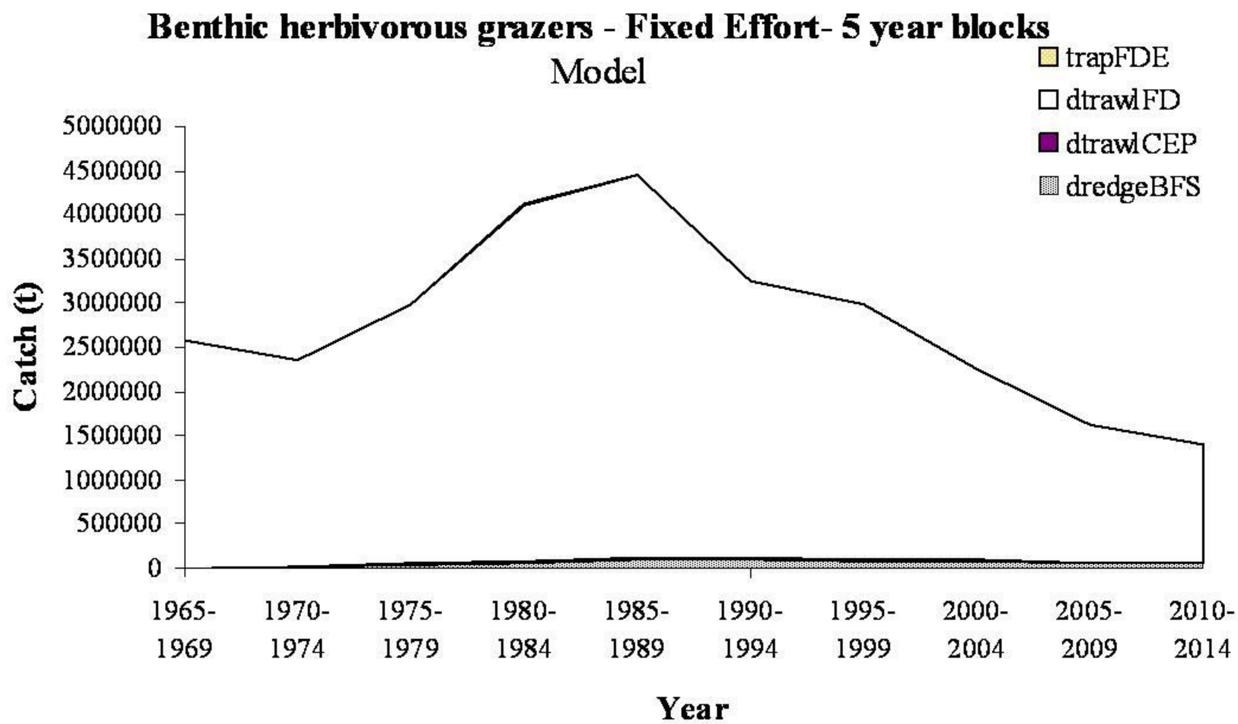


Figure D37. Benthic herbivorous grazers catch per fishery trajectory for Atlantis NEUS (fixed effort run). No observed time series was available.

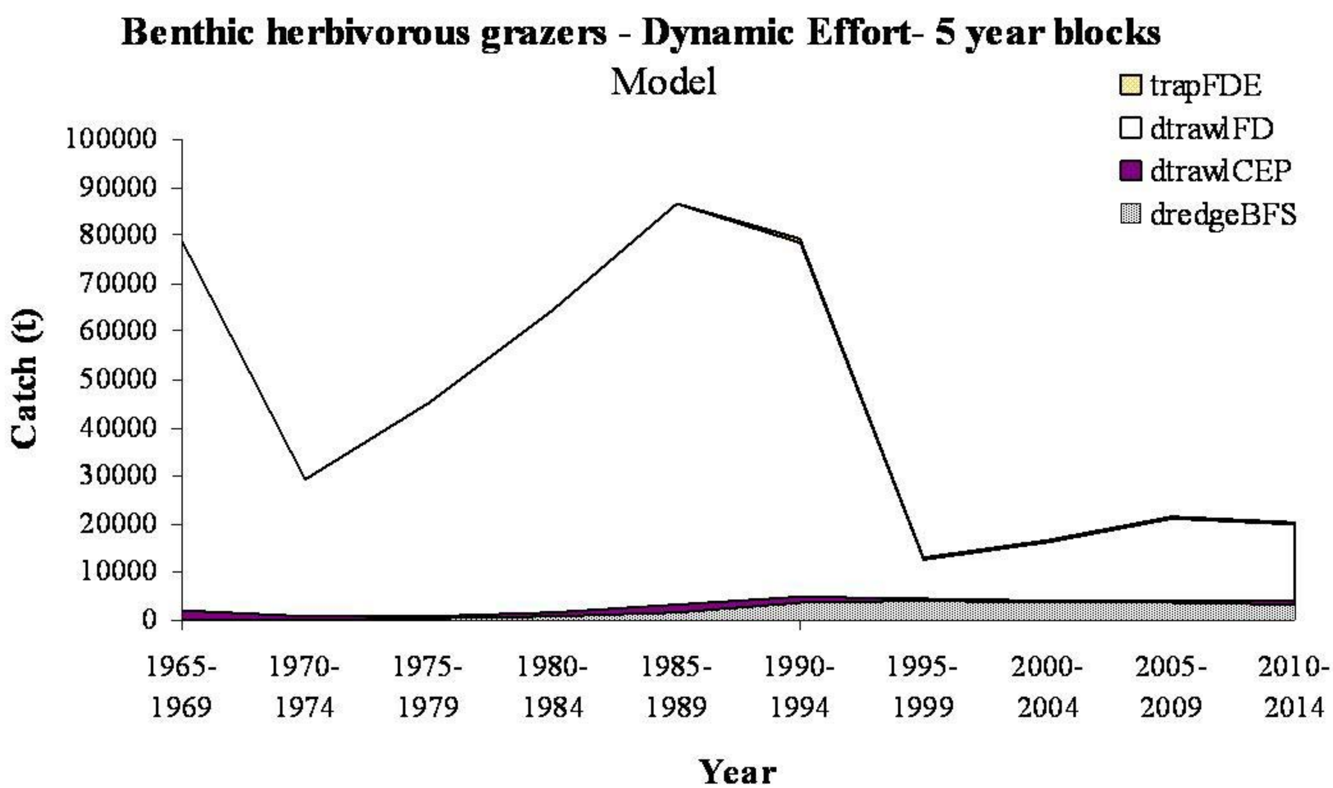
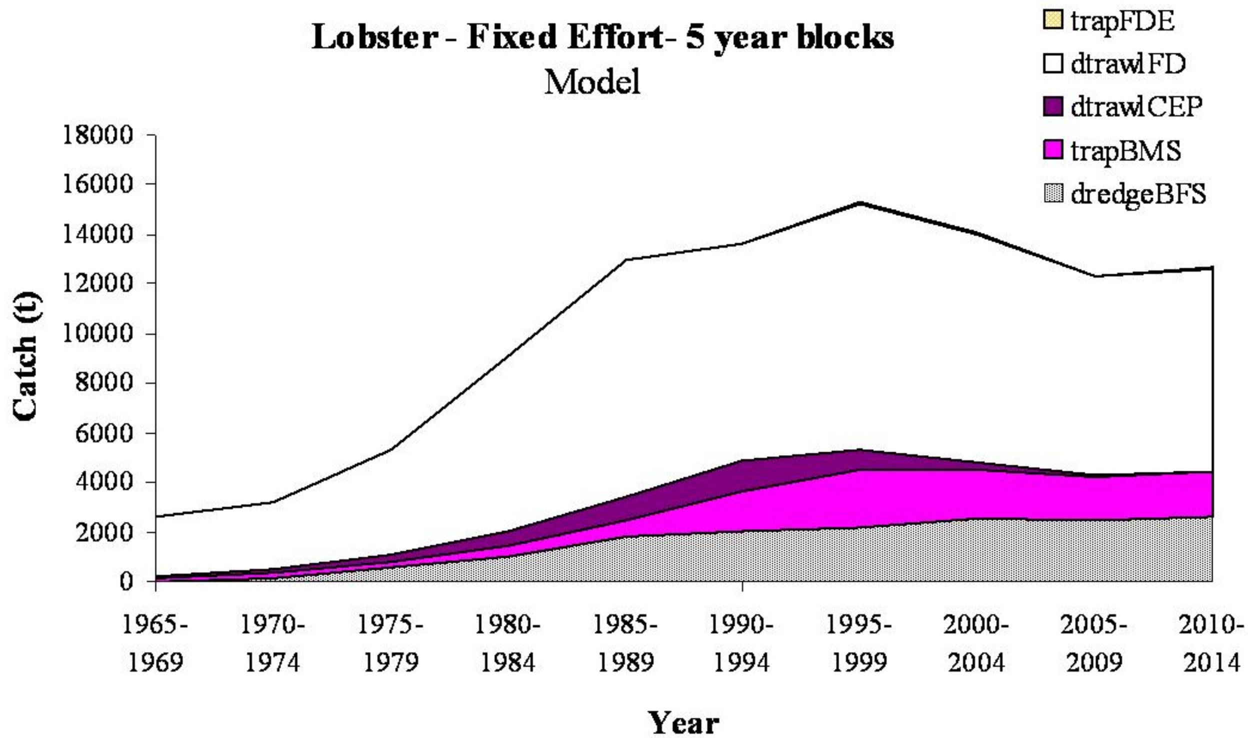


Figure D38. Benthic herbivorous grazers catch per fishery trajectory for Atlantis NEUS (dynamic effort run). No observed time series was available.



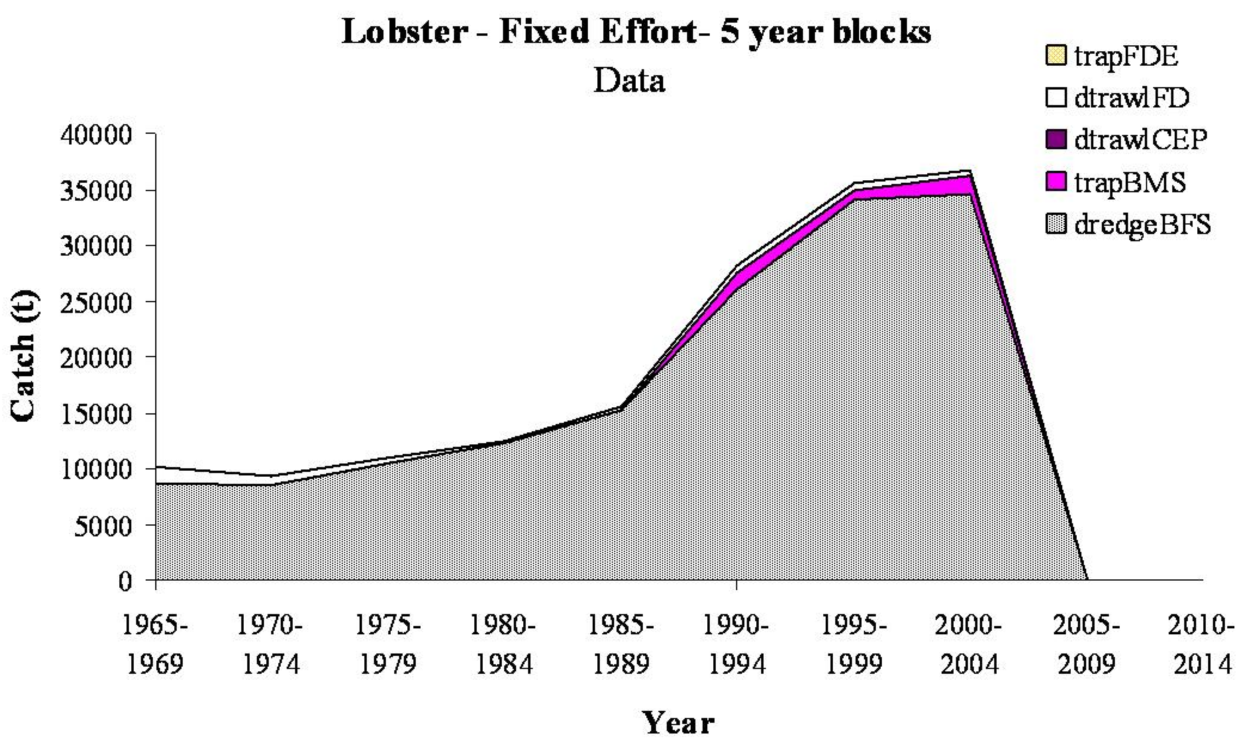
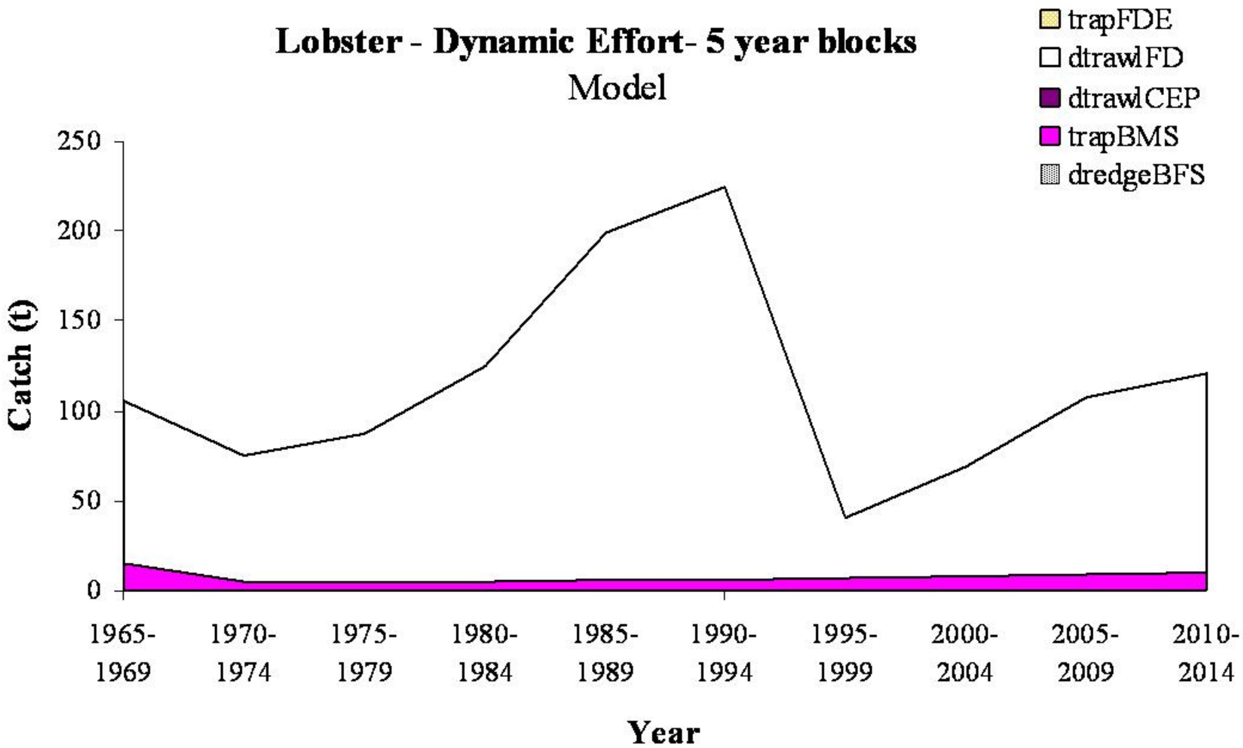


Figure D39. Lobster (*Homarus americanus*) catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



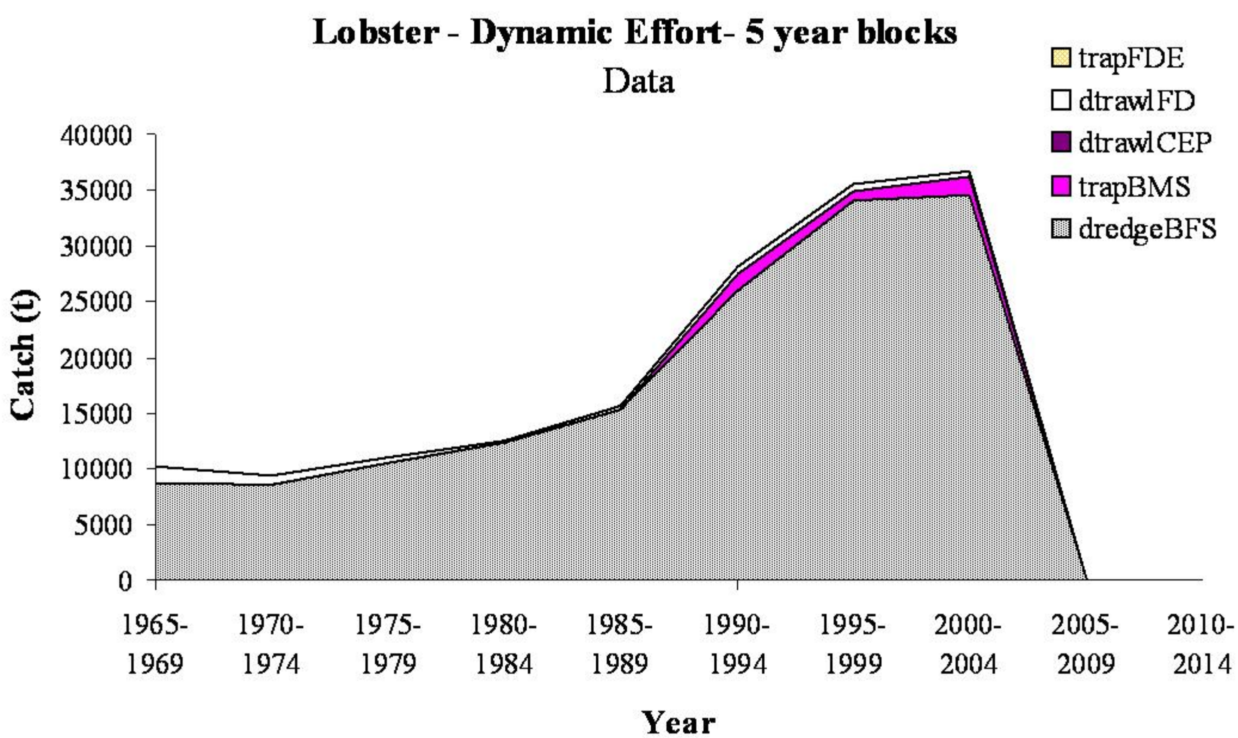
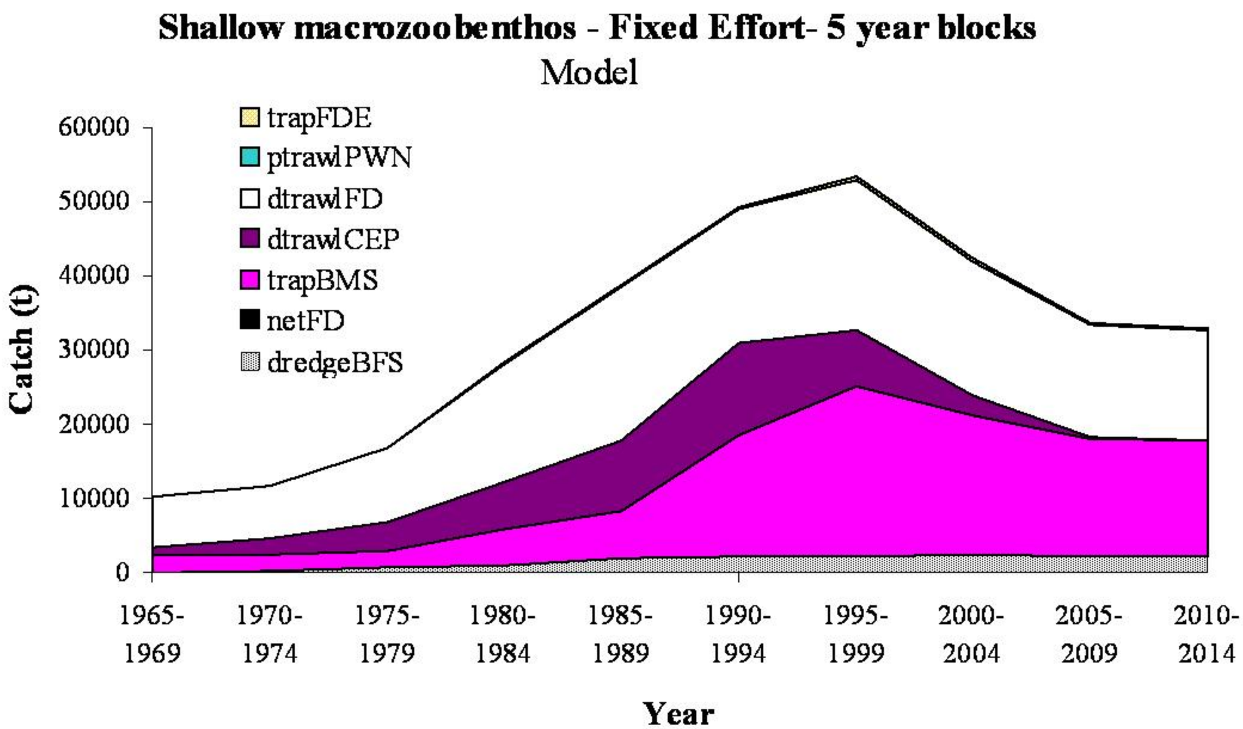


Figure D40. Lobster (*Homarus americanus*) catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.



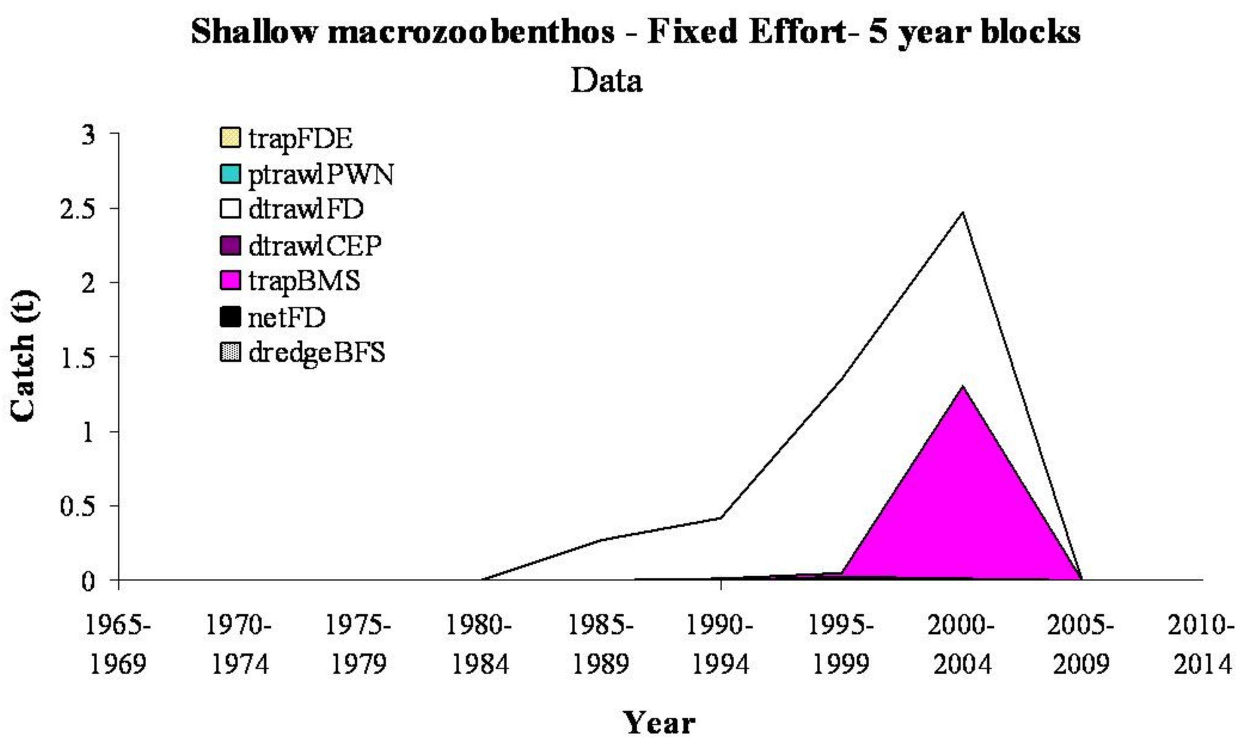
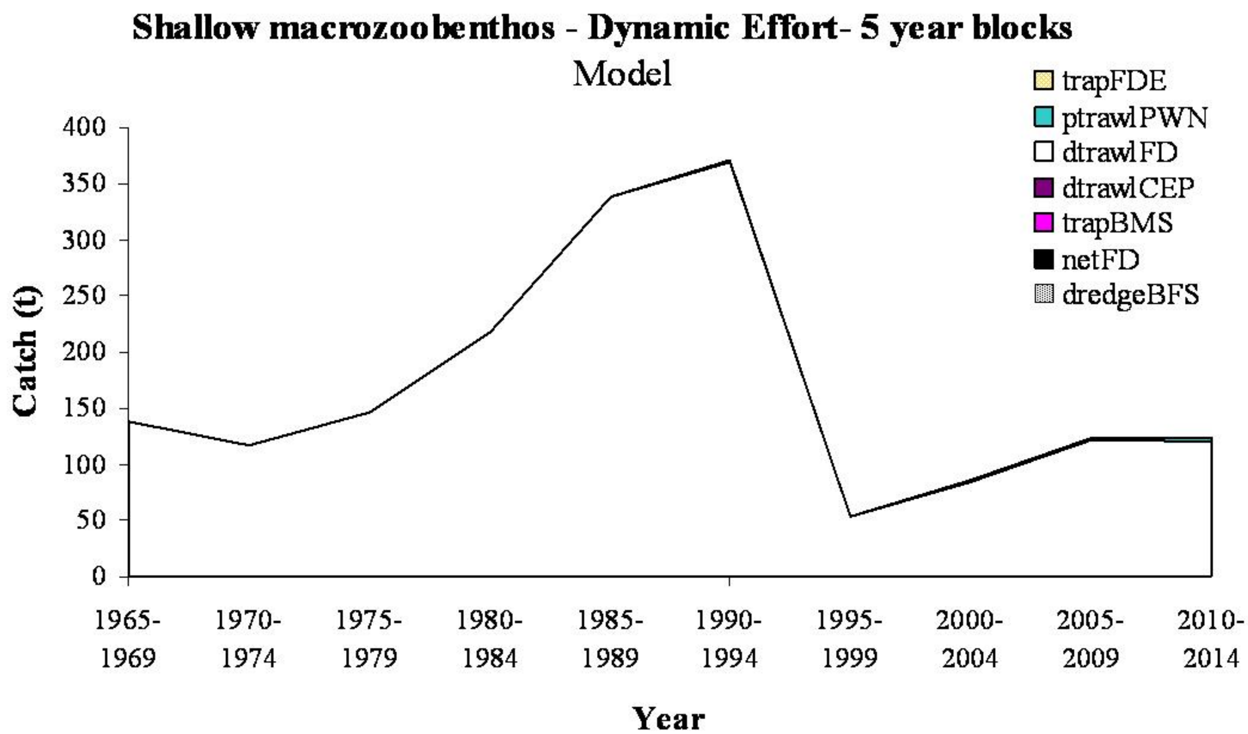


Figure D41. Shallow macrozoobenthos catch per fishery trajectories for both Atlantis NEUS (fixed effort run) and the actual observed time series.



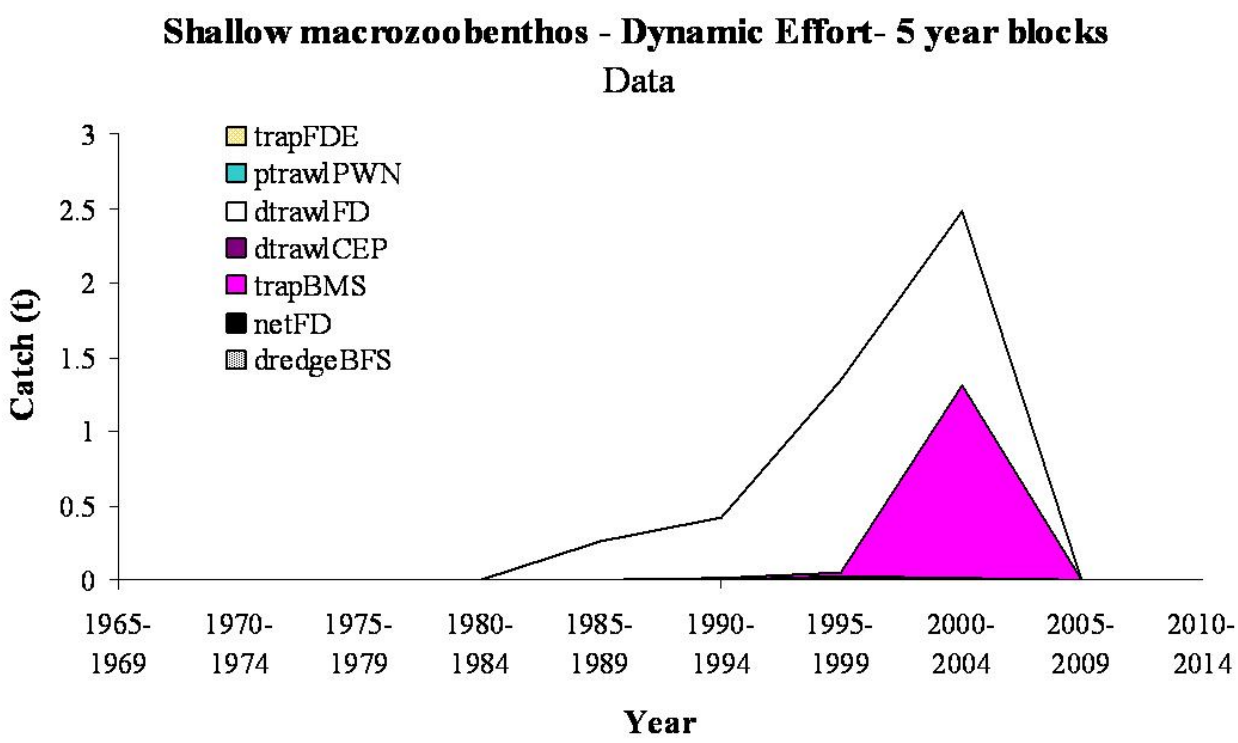


Figure D42. Shallow macrozoobenthos catch per fishery trajectories for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

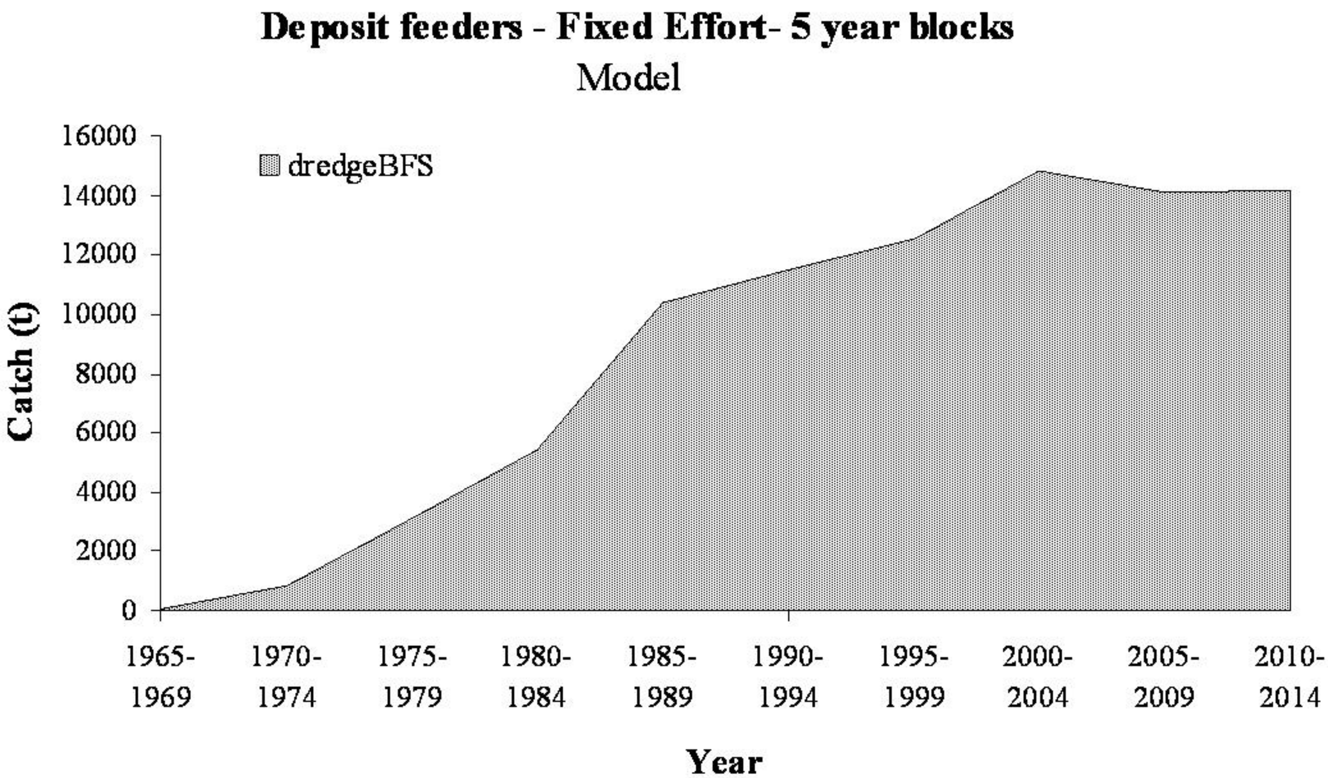


Figure D43. Deposit feeders catch per fishery trajectory for Atlantis NEUS (fixed effort run). No observed time series was available.

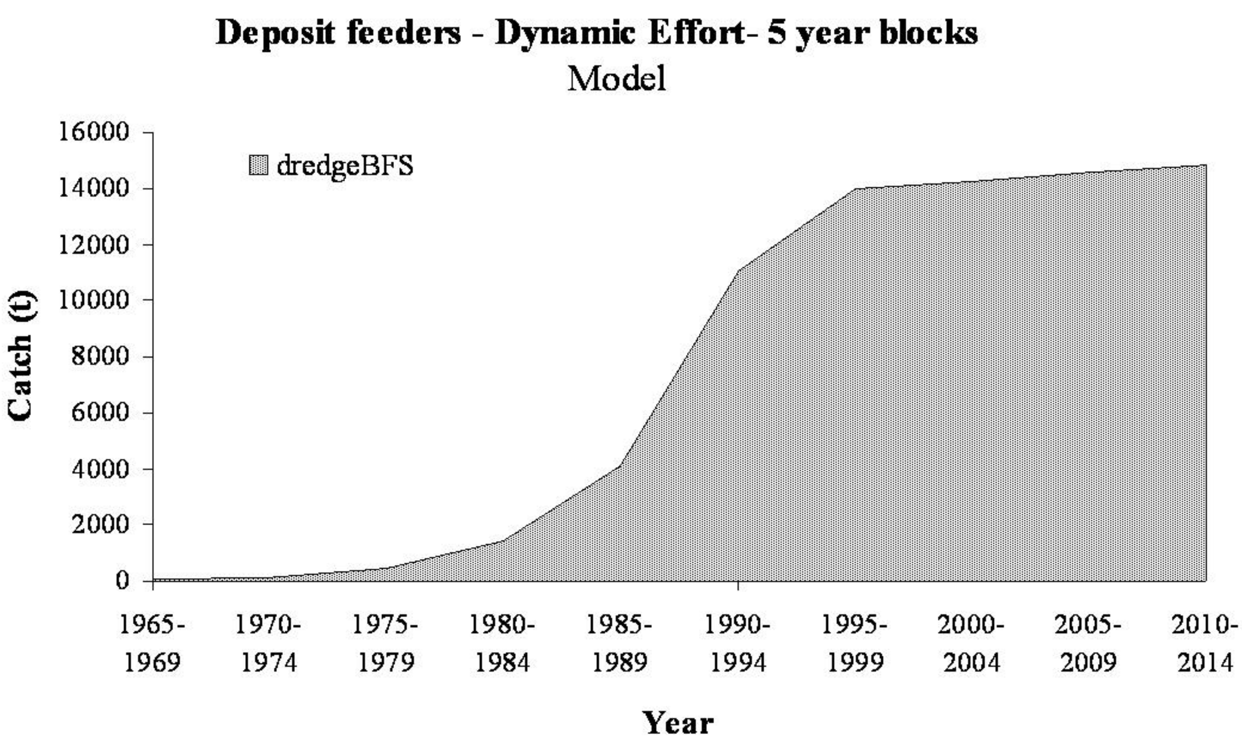


Figure D44. Deposit feeders catch per fishery trajectory for Atlantis NEUS (dynamic effort run). No observed time series was available.

APPENDIX E: Atlantis NEUS – EFFORT TRAJECTORY RESULTS

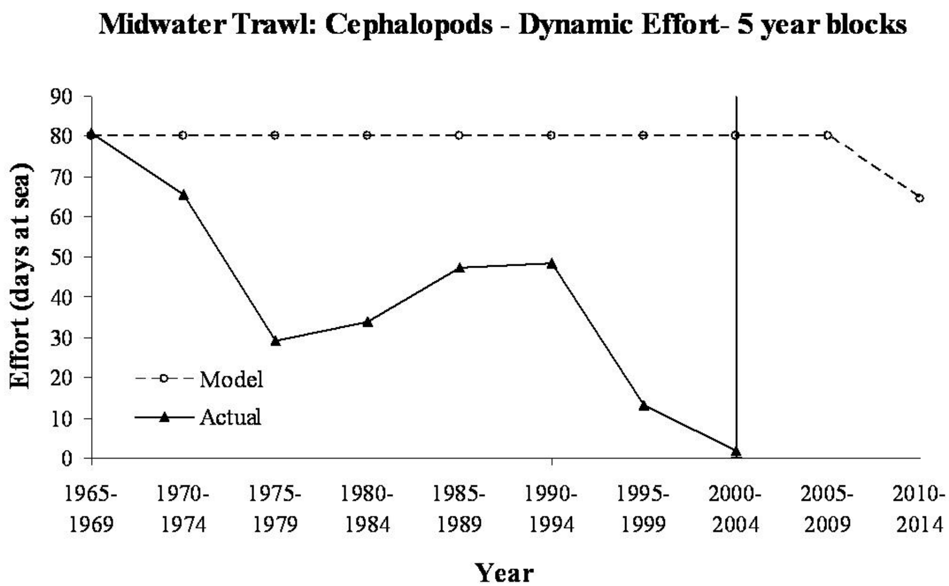


Figure E1. Effort trajectory for the midwater trawl on cephalopods for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

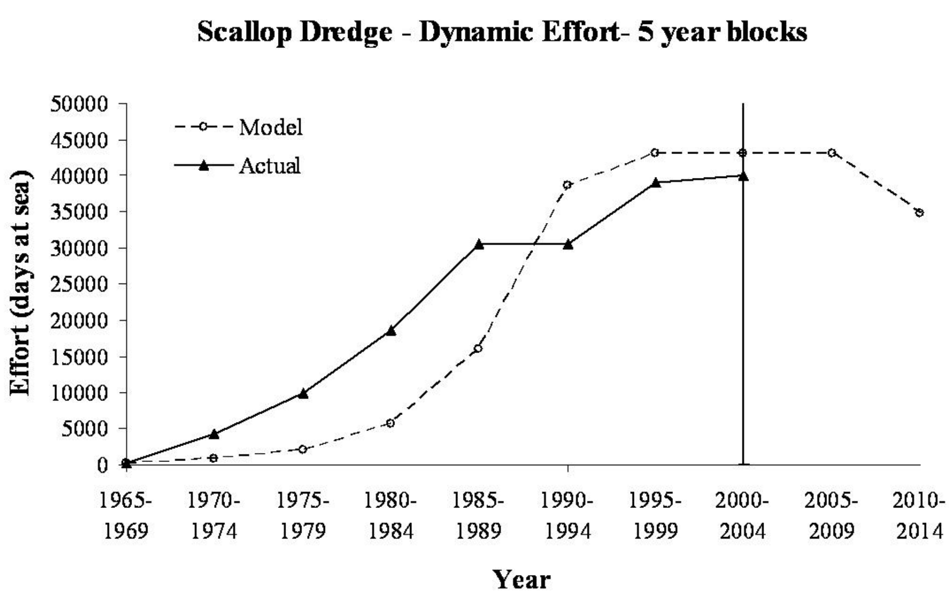


Figure E2. Effort trajectory for the scallop (*Placopecten magellanicus*) dredge for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

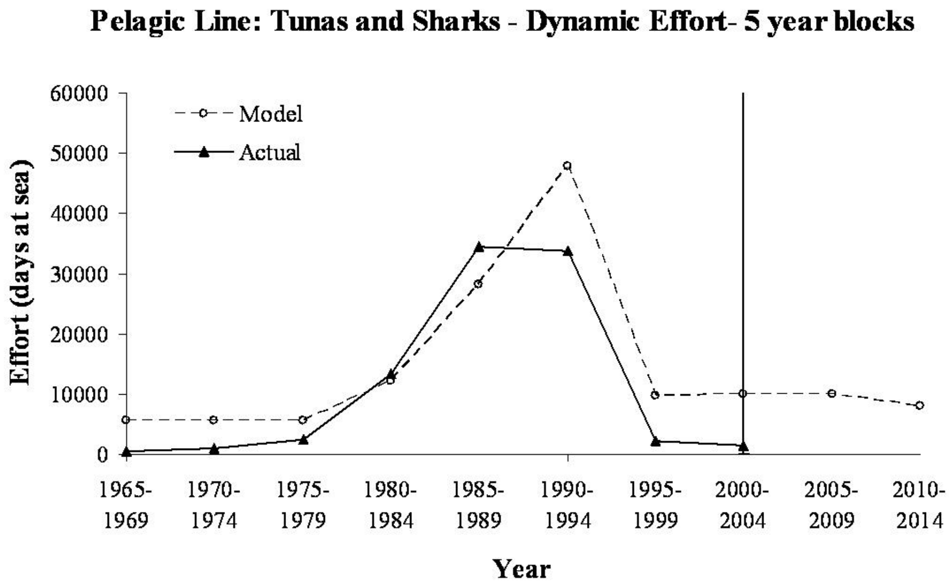


Figure E3. Effort trajectory for the pelagic line fishery on tunas and sharks for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

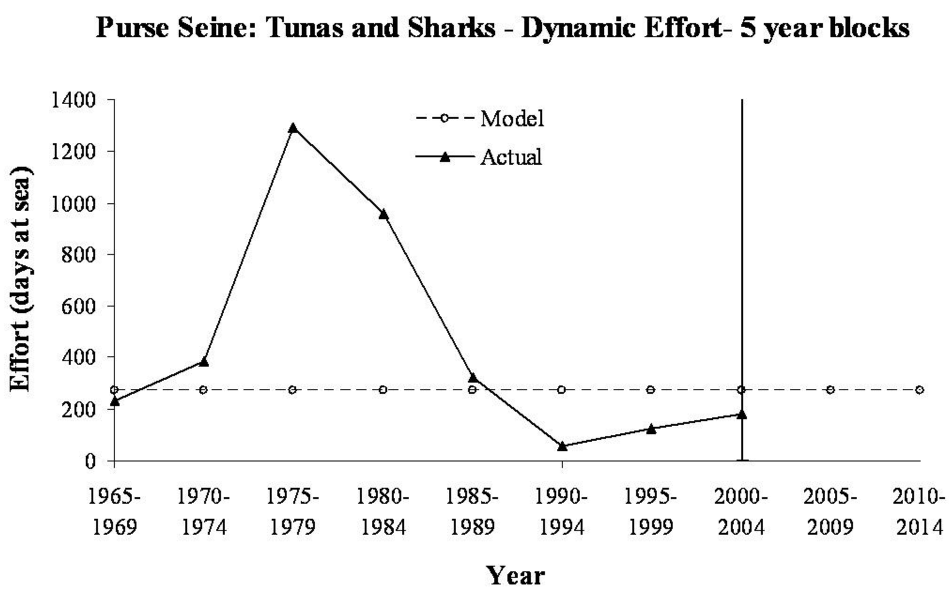


Figure E4. Effort trajectory for the purse seine on tunas and sharks for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

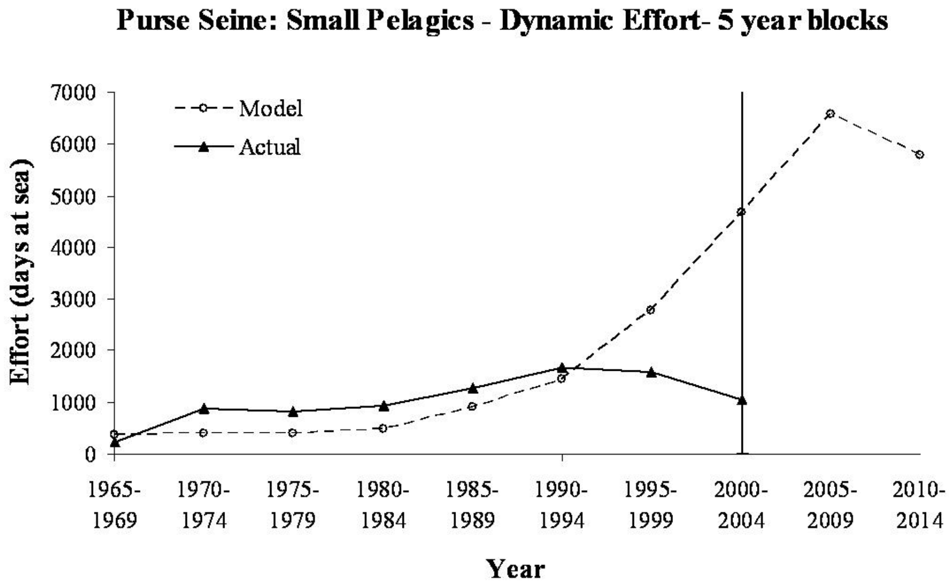


Figure E5. Effort trajectory for the purse seine on small pelagics for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

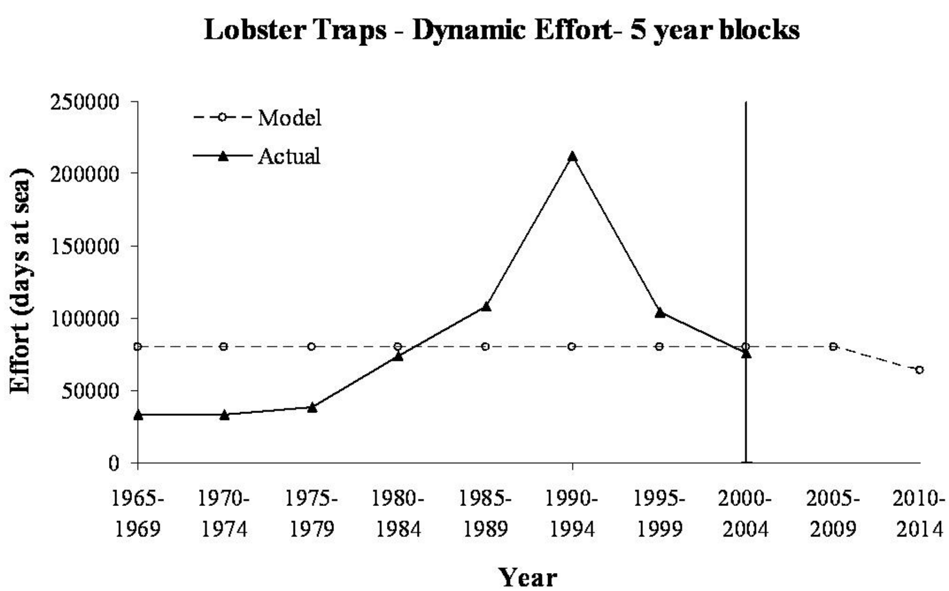


Figure E6. Effort trajectory for lobster (*Homarus americanus*) traps for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

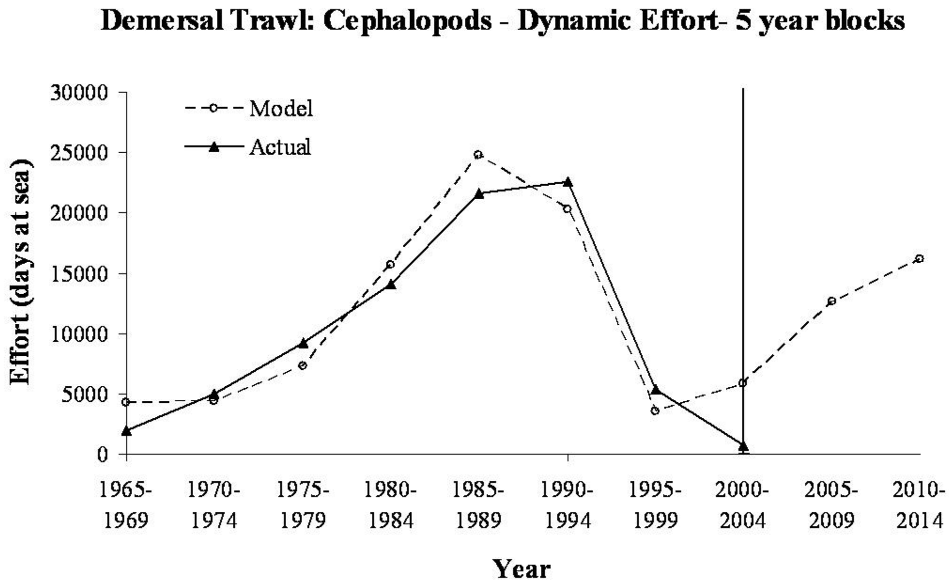


Figure E7. Effort trajectory for the demersal trawl on cephalopods for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

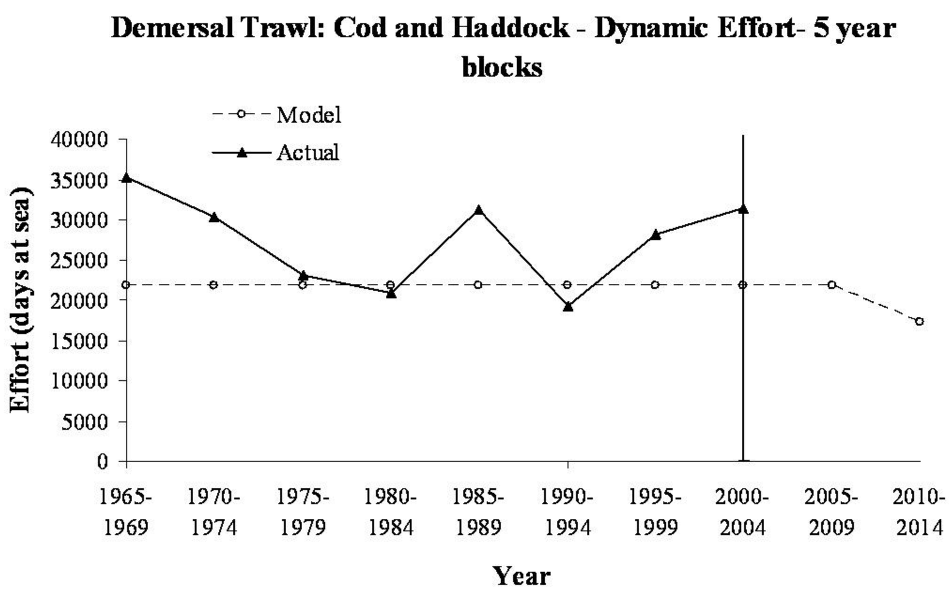


Figure E8. Effort trajectory for the demersal trawl on cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

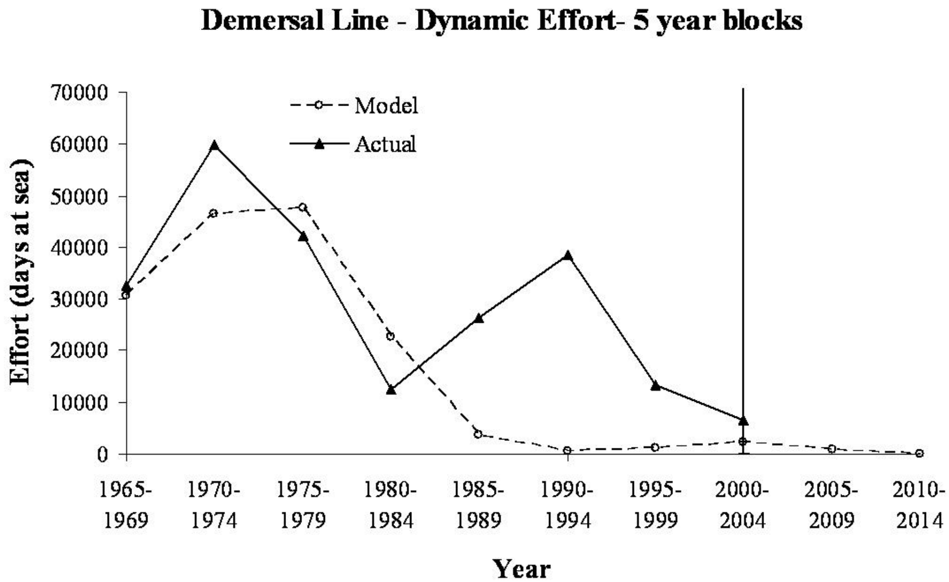


Figure E9. Effort trajectory for the demersal line fishery for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

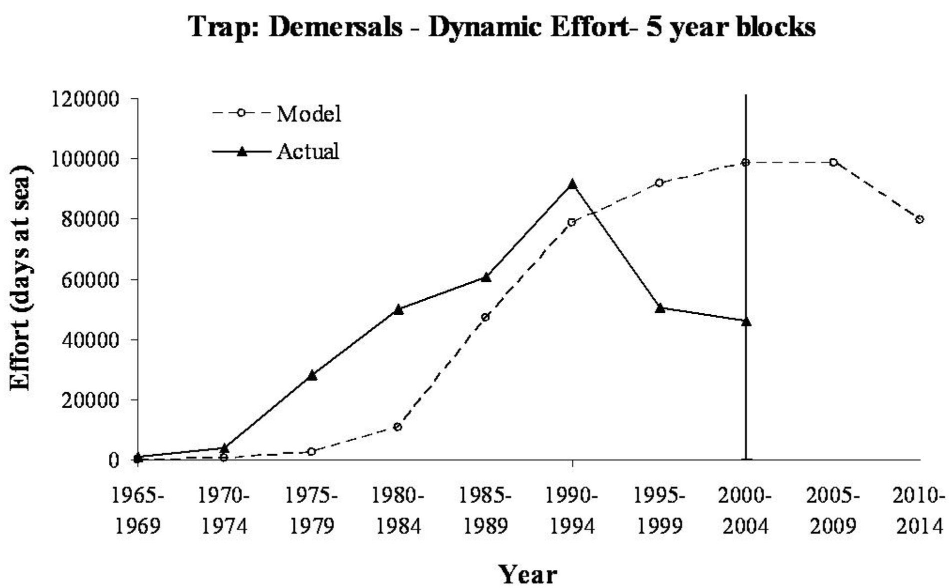


Figure E10. Effort trajectory for the trap on demersals fishery for both Atlantis NEUS (dynamic effort run) and the actual observed time series.

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